ENVIRONMENTAL VALUE ENGINEERING (EVE): A SYSTEM FOR ANALYZING THE ENVIRONMENTAL IMPACT OF BUILT ENVIRONMENT ALTERNATIVES

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1992

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by

Wilfred H. Roudebush

To my wife, Christine; my children, Jennifer, Sarah, Matthew, and Kelly; my parents, Betty and Ernest; and the late Anthony Section.

ACKNOWLEDGEMENTS

I would like to express appreciation to my supervisory committee chairman, Dr. John F. Alexander, Jr., for his guidance, patience, and encouragement during the research and documentation for this dissertation.

Acknowledgement is also due committee member Dr. Howard T. Odum of the University of Florida for his example and extraordinary contribution of the energy basis of man and nature. His research on EMERGY analysis forms the main basis for this study on "environmental value engineering".

Numerous contributions also were made by the other members of my committee: Dr. Charles J. Kibert provided expertise on the value engineering basis of environmental value engineering; Dr. Weilin P. Chang provided valuable input and financial support in the form of graduate teaching and research assistantships; and Dr. Gary J. Koehler assisted with input and expertise in knowledge-based expert systems for future applications of environmental value engineering.

Most importantly, I want to thank my wife, Christine. Development of environmental value engineering would not have been possible without her love, understanding, and dedication to family.

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Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

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December 1992

Chairman: John F. Alexander, Jr.
Major Department: College of Architecture

An analysis system called environmental value engineering was developed to analyze the environmental impact of built environment alternatives. This evaluation system combines Dr. Howard T. Odum's EMERGY analysis with traditional value engineering. The procedure compares multiple built environment alternatives over a life cycle consisting of 10 phases: natural resource formation, natural resource exploration and extraction, material production, design, component production, construction, use, demolition, natural resource recycling, and disposal. Because these phases successively accumulate the results of work, EMERGY tends to increase with each phase. Embodied energy in BTUs of coal equivalent has been used to evaluate energy inputs to alternatives; EMERGY is more complete by including environmental work and other nonfuel inputs as either contributions or losses due to environmental impact. This dissertation applies the new evaluation procedure to two alternative exterior wall construction systems of concrete masonry units and concrete tilt-up panels.

Energy systems diagrams (models) and language were used to represent detailed and aggregated EMERGY inputs. Inputs were calculated on EMERGY analysis tables. Data from calculations were input into a DYNAMO simulation program.

The evaluation procedure was used to evaluate alternatives with detailed and aggregated EMERGY tables and signatures. Simulation results included graphical output of cumulative EMERGY.

Environmental value engineering EMERGY indices were used to compare EMERGY per unit of built environment alternative. The highest environmental impact occurred during the first three phases of material transformity for both alternatives, with 56% of total EMERGY for the concrete masonry unit (CMU) alternative and 69% for the concrete tilt-up panel alternative. The EMERGY per unit of built environment alternative was 2.35E13 solar emjoules (SEJ) per square foot for the CMU alternative and 2.10E13 SEJ per square foot for the concrete tilt-up panel alternative. Environmental impact of the CMU alternative was 11.9% higher.

Sustainable develoment selection of built environment alternatives which contribute the most EMERGY to the economy while drawing the least from it are possible through use of environmental value engineering.

CHAPTER 1
INTRODUCTION

As the earth's environment becomes crowded with increasing population and the resources of the earth scarce, efficient and economic building construction becomes increasingly important. This dissertation compares new and old ways for evaluating the requirements and contributions of the built environment so as to better include the environment and resource values. Traditional systems of evaluation using dollar cost are compared with a method that uses EMERGY, the prior work of nature in developing the land and other resources and also the human services used. EMERGY evaluation is incorporated into a new computer aided procedure for evaluating built environment alternatives. Comparisons were made of exterior wall construction as an example.

The sustainability of humans on this planet is directly affected by the environmental impact of economic development in the form of our built environment. A range of environmental issues are impacted by the built environment: natural resource use, solid waste generation, wetlands destruction, air/water/noise pollution, hazardous waste generation/disposal, plant/wildlife destruction, ozone depletion, coastal zone effects, the greenhouse effect, and global warming (Kibert, Roudebush, & Waller, 1991).

The operation of technological societies is dependent upon the good use of the earth's resources and on economic developments that are compatible. Faced with shortages of natural resources, pollution, overgrowth, and concern for protecting the environment, human beings are coming to realize that new concepts are needed to analyze the interdependent parts of the built environment as a whole. This study considers a new analysis concept for evaluating the environmental impact of built environment alternatives.

Statement of the Problem

The new analysis concept must overcome the shortcomings of traditional analysis systems. These shortcomings include:

1. too much concentration on the interdependent parts of built environment alternatives during specific analysis periods;
2. analysis periods too short to represent the total life cycle of built environment alternatives;
3. use of money or embodied energy measures that do not evaluate environmental work appropriately; and
4. lack of consideration of the environmental impact of all built environment alternative inputs.

In this research an analysis system was developed without these shortcomings and given the name "environmental value engineering". Work was done in four stages: 1) environmental impacts of built environment input were identified, 2) traditional analysis systems were surveyed for procedures which could be incorporated into environmental value engineering, 3) procedures were written for environmental value engineering including a simulation program, and 4) the environmental value engineering was applied to a case study application.

Organization of the Study

Chapter 1 contains an introduction to the study, a statement of the problem and purpose of the study, environmental value engineering concepts and definitions, introduction of the case study application, and state-of-the-art review of analysis systems related to environmental value engineering and the analysis of built environment alternatives.

Chapter 2 presents detailed and aggregated environmental impact EMERGY input calculation and analysis methods used in an environmental value engineering analysis, development of a simulation program for input of environmental impact EMERGY data for built environment alternatives, and a case study application.

The results of this case study application are presented in Chapter 3 in the form of EMERGY input source data tables, EMERGY input signatures, and comparisons of built environment alternative systems and alternatives.

Chapter 4 presents a discussion of the case study application, environmental value engineering implementation, and recommendations for future research and applications.

Concepts and Definitions

Built Environment Inputs

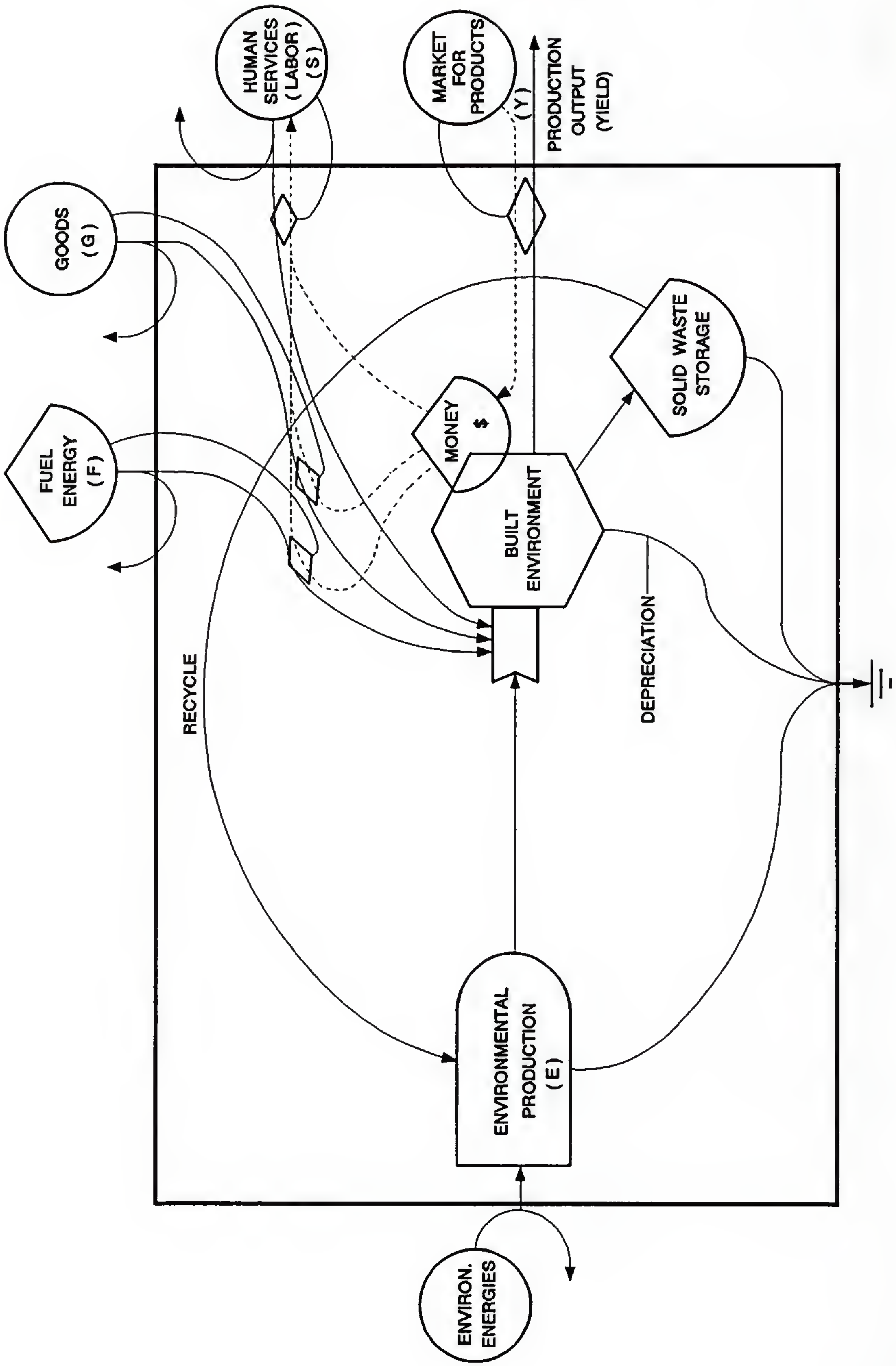
The term "built environment", as used in this dissertation, includes all human-made objects (alternatives) on earth that consume environment (E), fuel energy (F), goods (G), and services (S) inputs. This is represented in the energy systems diagram of Figure 1-1 using energy systems language explained in methods. Money circulates into the system to pay only for services (labor) rendered by human population. Money is not paid to the environment, and money that is paid to people cannot be used to evaluate benefits or losses to the environment.

Environmental Value Engineering

An analysis system called environmental value engineering was developed to analyze the environmental role of built environment alternatives. This evaluation system combines Howard T. Odum's EMERGY analysis with traditional value engineering, listed in Figure 1-2.

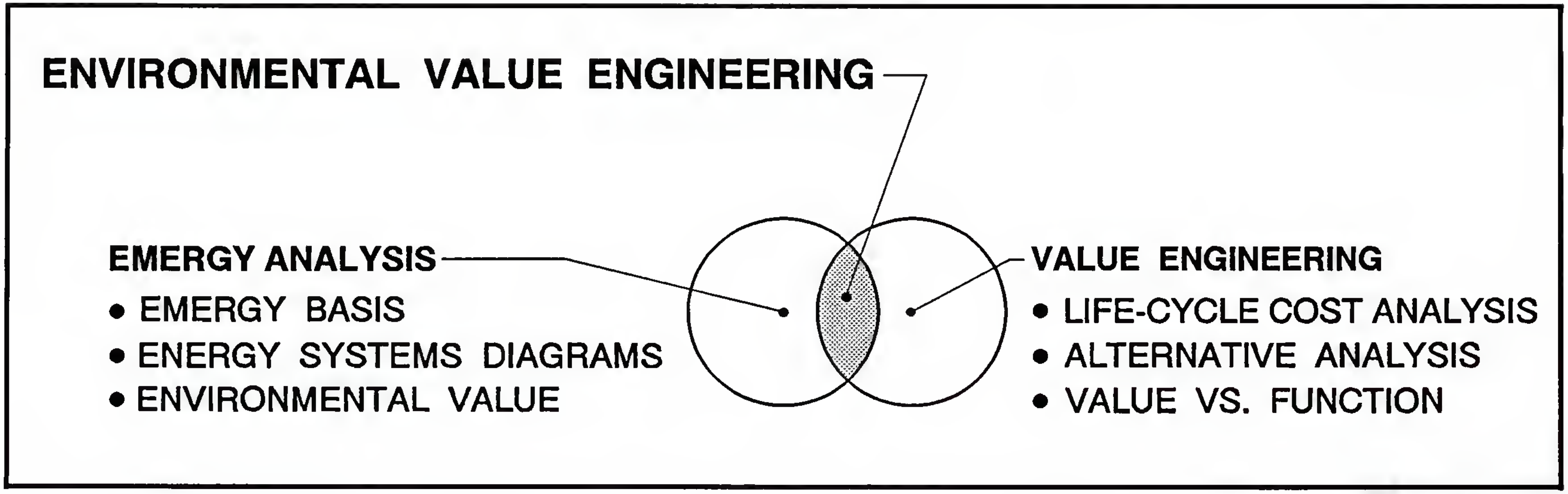
Life cycle, was defined to include all phases that a built environment alternative goes through, from natural resource formation to final disposition. A built environment alternative uses the earth's renewable and nonrenewable resources throughout its life cycle. Consumption of minerals and energy begins with the conception of a built environment alternative and continues beyond its use phase. For convenience, environmental value engineering has 10 built

Figure 1-1. Energy systems diagram of built environment.



HUMAN SERVICES (LABOR) (S)
MARKET FOR PRODUCTS
(Y)
PRODUCTION OUTPUT (YIELD)
GOODS (G)
FUEL ENERGY (F)
MONEY $
SOLID WASTE STORAGE
BUILT ENVIRONMENT
DEPRECIATION
RECYCLE
ENVIRONMENTAL PRODUCTION (E)
ENVIRON. ENERGIES

Figure 1-2. Environmental value engineering model.



ENVIRONMENTAL VALUE ENGINEERING

EMERGY ANALYSIS
- EMERGY BASIS
- ENERGY SYSTEMS DIAGRAMS
- ENVIRONMENTAL VALUE

VALUE ENGINEERING
- LIFE-CYCLE COST ANALYSIS
- ALTERNATIVE ANALYSIS
- VALUE VS. FUNCTION

environment alternative life cycle phases (Figure 1-3).

Traditional evaluation used money. Since money goes only to pay for human services, it was not suitable for environmental value engineering. Embodied energy could not be used either because it accounts only for fuel energy and does not include environmental, goods, or services input sources.

Since production and consumption processes, which take place during all phases of a built environment alternative's life cycle, use energy of differing quality or type, EMERGY was selected as the basic unit of quantification because it is energy of differing types into units of one type of energy. The name "EMERGY" was coined by David Scienceman in 1983 to distinguish it from other embodied energy concepts. Scienceman (1987) documented the nomenclature of energy and EMERGY. So as not to confuse EMERGY with energy, the word EMERGY is capitalized in this dissertation. Solar emjoules (sej) are the units of solar EMERGY, used in environmental value engineering.

Environmental value engineering evaluates the environmental contribution and impact of built environment alternatives in units of solar EMERGY over the life cycle. The sum of EMERGY contributions to each phase is added as an input to the next. EMERGY accumulates from one phase to the next. "EMERGY is not only a measure of what went into a product, it is a measure of the useful contributions which can be expected from that product as an economy self organizes for maximum production" (Odum, 1991, p. 91). An alternative is best which

Figure 1-3. Environmental value engineering phases of life cycle.

NATURAL RESOURCE FORMATION	PHASE A
NATURAL RESOURCE EXPLORATION AND EXTRACTION	PHASE B
MATERIAL PRODUCTION	PHASE C
DESIGN	PHASE D
COMPONENT PRODUCTION	PHASE E
CONSTRUCTION	PHASE F
USE	PHASE G
DEMOLITION	PHASE H
NATURAL RESOURCE RECYCLING	PHASE I
DISPOSAL	PHASE J

contributes most while drawing the least from the main economy.

Concept of Maximum Benefit

"In any environmental development there is an optimal intensity which generates maximum EMERGY, part from the environmental work and part from purchased inputs" (Odum, 1991, p. 67). According to Odum (1991), there are several maxima of concern:

1. The development intensity that maximizes yield and profit.
2. The development intensity that maximizes the total EMERGY availability to the home country.
3. The development intensity that maximizes the EMERGY of investing countries.
4. The development intensity that maximizes the total EMERGY production and use worldwide.

Built environment alternatives which contribute the most EMERGY to the economy while drawing the least from it provide maximum benefit.

Environmental Value Engineering Phases of Life Cycle

The analysis period of environmental value engineering is subdivided into 10 phases through which built environment alternative materials, components, and systems proceed. This is a distinct difference between environmental value engineering and other analysis systems.

The analysis period of traditional value engineering is limited to the construction phase and a "study period" portion of the use phase. The study period generally is 25-40 years, which is considerably less than the life cycle of a built environment alternative.

The study period of materials analyzed in the American Institute of Architects' (1992, April) issue of Environmental Resource Guide Subscription is more extensive than traditional value engineering but does not include all phases of the life cycle, nor does it analyze all systems of a built environment alternative. The 10 phases of environmental value engineering are based upon different production and consumption processes taking place within each phase. These production and consumption processes have distinct environment (E), fuel energy (F), goods (G), and services (S) environmental impact input source requirements. For example, the following are inputs accounted for during construction phase F:

E. Environment (renewable)
    E1. Atmosphere
    E2. Ecological production
    E3. Energy
        1. Sun
        2. Earth
    E4. Land
        1. Area
        2. Resources
    E5. Water
        1. Area
        2. Resources
F. Fuel energy (nonrenewable)
    F1. Equipment
    F2. Facilities
G. Goods
    G1. Equipment
    G2. Facilities
    G3. Materials
    G4. Tools

S. Services
  S1. Labor

A list of environmental impact EMERGY input sources for all 10 environmental value engineering phases is provided in Appendix B.

The production and consumption processes of the 10 phases of environmental value engineering are described in the following subsections.

Phase A: natural resource formation

The natural resource formation phase involves the production and consumption of various environmental systems (ecosystems, geology systems, etc.). Natural resources utilized in built environment alternatives include minerals, which are formed by earth processes over millions of years, and biomass, resulting from living organism net production occurring over shorter periods of time.

Phase B: natural resource exploration and extraction

The natural resource exploration and extraction phase includes EMERGY of environment, fuel energy, goods, and services inputs occurring during natural resource exploration and extraction processes. Also, environmental impacts assignable to this phase include renewable environmental inputs in the form of land used during extraction and storage of extracted natural resources. Reclamation of land, after natural resource extraction, and transportation of natural resources for material production is included here. These environmental impacts may increase in the future.

Phase C: material production

The material production phase includes EMERGY of environment, fuel energy, goods, and services inputs occurring during material production. Material production includes the conversion of natural resources into materials used in built environment alternative component production. Some materials are produced directly into standardized components. Examples of standardized components are steel beams, doors, windows, dimensional lumber, and roofing components. Many components of a built environment alternative are not produced until specific design information has been provided.

Phase D: design

The design phase includes EMERGY of environment, fuel energy, goods, and services inputs occurring during architectural and engineering design. The design phase includes five subphases. According to the American Institute of Architects (1987), these subphases are: 1) schematic design, 2) design development, 3) construction documents, 4) bidding and negotiations, and 5) construction administration.

Phase E: component production

The component production phase includes EMERGY of environment, fuel energy, goods, and services inputs occurring during component production. Some standard components are produced and stored, before use, while other components are obtained as needed. Component production is conducted by manufacturing facilities specializing in various built environment alternative components.

Production of components specifically designed for a built environment alternative proceed upon completion and acceptance of production documents during the construction administration subphase of design, which overlaps with the construction phase. Components produced at the job site are included in the construction phase instead of the component production phase. For example, concrete tilt-up exterior wall panels are produced during the construction phase. This phase includes the environmental impacts related to transportation of the various components to the built environment alternative site for construction.

Phase F: construction

During construction materials, components, and systems are assembled through the use of environment, fuel energy, goods, and services inputs into structures. Environment, fuel energy, goods, and services inputs used during this phase are dependent upon such factors as type of construction, techniques of construction, time of construction, quality of materials, components and systems, and workmanship.

During the construction phase, there are wastes and their impacts are to be evaluated. This phase includes work done during the guarantee and warranty periods of the construction contract, which commence at the beginning of the built environment alternative use phase.

Phase G: use

The use phase includes EMERGY of environment, fuel energy, goods, and services inputs occurring during use, operation, and maintenance up to time of demolition. Included are financing, maintenance, operation, alteration, repair, replacement, tax elements, insurance, and any other activities which require EMERGY inputs.

The use phase includes the period of time from substantial completion of construction to the demolition phase. Included are periods of nonuse or abandonment. The use phase is affected by quality, occupancy, time of use, and decisions on recycling or disposal of materials, components, and systems.

Phase H: demolition

The demolition phase includes EMERGY evaluation of environment, fuel energy, goods, and services inputs used to demolish and remove the materials, components, and systems. The EMERGY evaluation is sensitive to decisions on reuse and recycling.

Currently, most built environment alternative materials, components, and systems are disposed of in the form of demolition debris during the demolition phase. Disposal of this demolition debris affects land use because one cubic yard of landfill is required for each 1000 to 1200 pounds of demolition debris (Appendix F). The EMERGY for disposals is accounted for in phase J (disposal phase). As land becomes less available for disposal of demolition debris, environmental policies related to the built environment will affect the selection of materials, components, and systems (Roudebush, 1991).

Phase I: natural resource recycling

The natural resource recycling phase includes the EMERGY of environment, fuel energy, goods, and services inputs used to recycle materials, components, and systems. The stored EMERGY of a built environment alternative may be reduced by transporting components away during the natural resource recycling phase. EMERGY can be saved if recycling increases natural resource formation (Phase A), and decreases natural resource exploration and extraction (Phase B), material production (Phase C), and component production (Phase E) requirements of future construction alternatives. Land area made available by recycling and disposal phases reduces the requirements for new land.

Salvage of demolition debris for recycling reduces the EMERGY required for disposal and landfill land use. Thus there is an EMERGY credit for salvage of demolition debris. Resource recycling during any phase of environmental value engineering reduces total EMERGY required.

The natural resource recycling phase of a built environment alternative is similar to the nutrient feedback phase of natural systems. System designs that maximize empower (EMERGY flux) are also the systems that feed back to the larger system of which they are a part (Odum, 1988). Disposal of built environment alternative materials, components, and systems with stored EMERGY affects sustainable development (Chapter 4).

Phase J: disposal

The disposal phase includes EMERGY of environment, fuel energy, goods, and services inputs occurring during the disposal of materials, components, and systems. Included in the evaluation are demolition debris placement, demolition debris compaction, demolition debris landfill containment, landfill closure, and landfill postclosure. According to Topp (1985), landfill closure and postclosure include groundwater monitoring, final cover, contour grading, surface water diversion, gas mitigation control, revegetation, security systems, and certification of closure. The EMERGY of these uses must be included.

Land use for disposal of demolition debris will become more important in the future. The EMERGY of land will increase as intensity of land use increases with population growth. Cumulative EMERGY of lands and their stored demolition debris measures the environmental impact and loss of resource contribution.

Hierarchical Organization

Environmental value engineering synthesizes the total EMERGY of all systems of a built environment during the 10 environmental value engineering life cycle phases. Each phase of a built environment alternative forms a portion of an EMERGY hierarchy for that alternative. It appears to be an example of an energy transformation hierarchy (Odum, 1991). Figure 1-4 depicts an energy hierarchy with 10% efficiency for each energy transformation step (Odum, 1991). The built

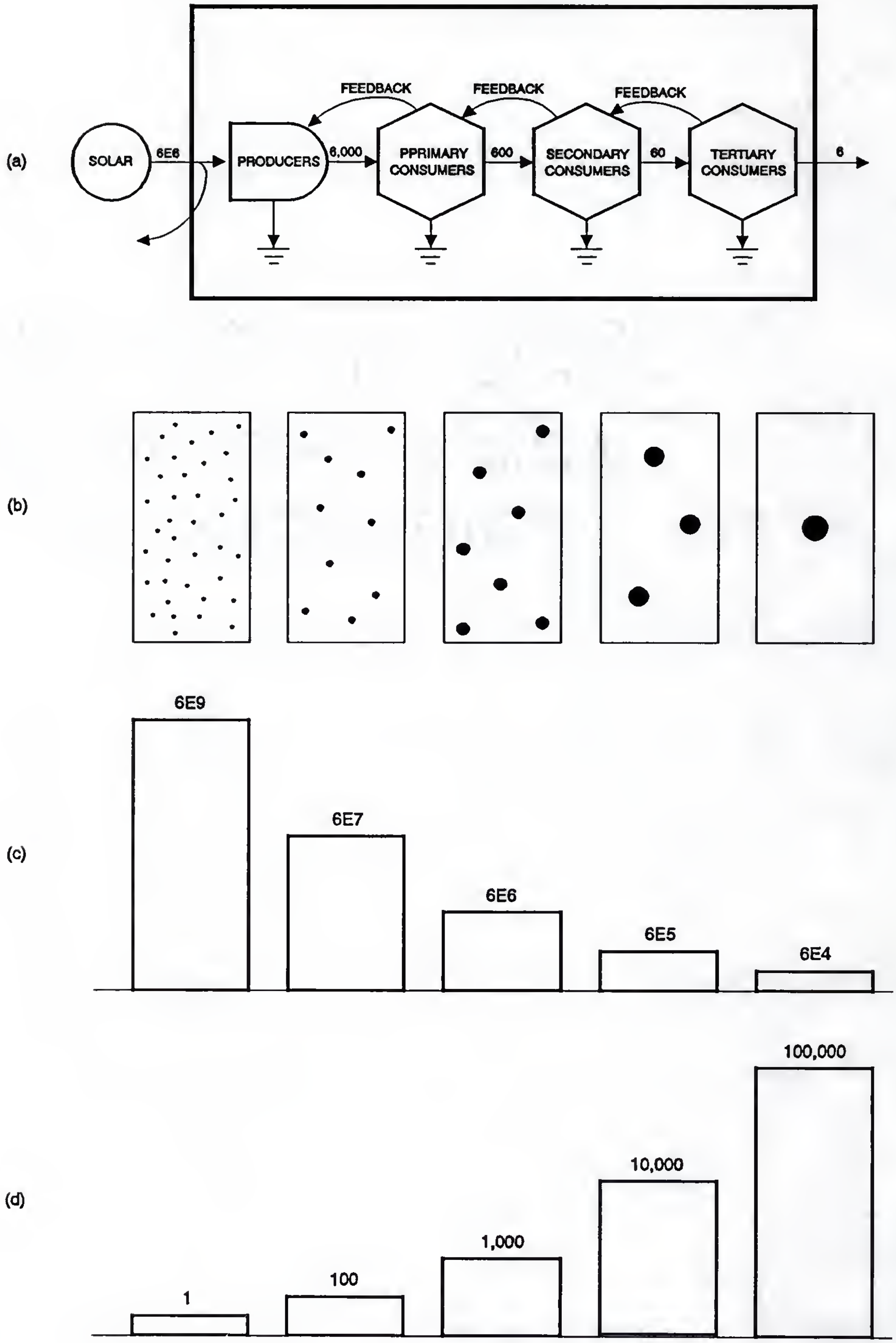
Figure 1-4. Energy hierarchy.

(a) Energy transformation diagram.

(b) Distribution of size and spatial pattern of units in each category.

(c) Graph of energy flows at each stage in the energy hierarchy.

(d) Solar transformities for each position in the hierarchy.

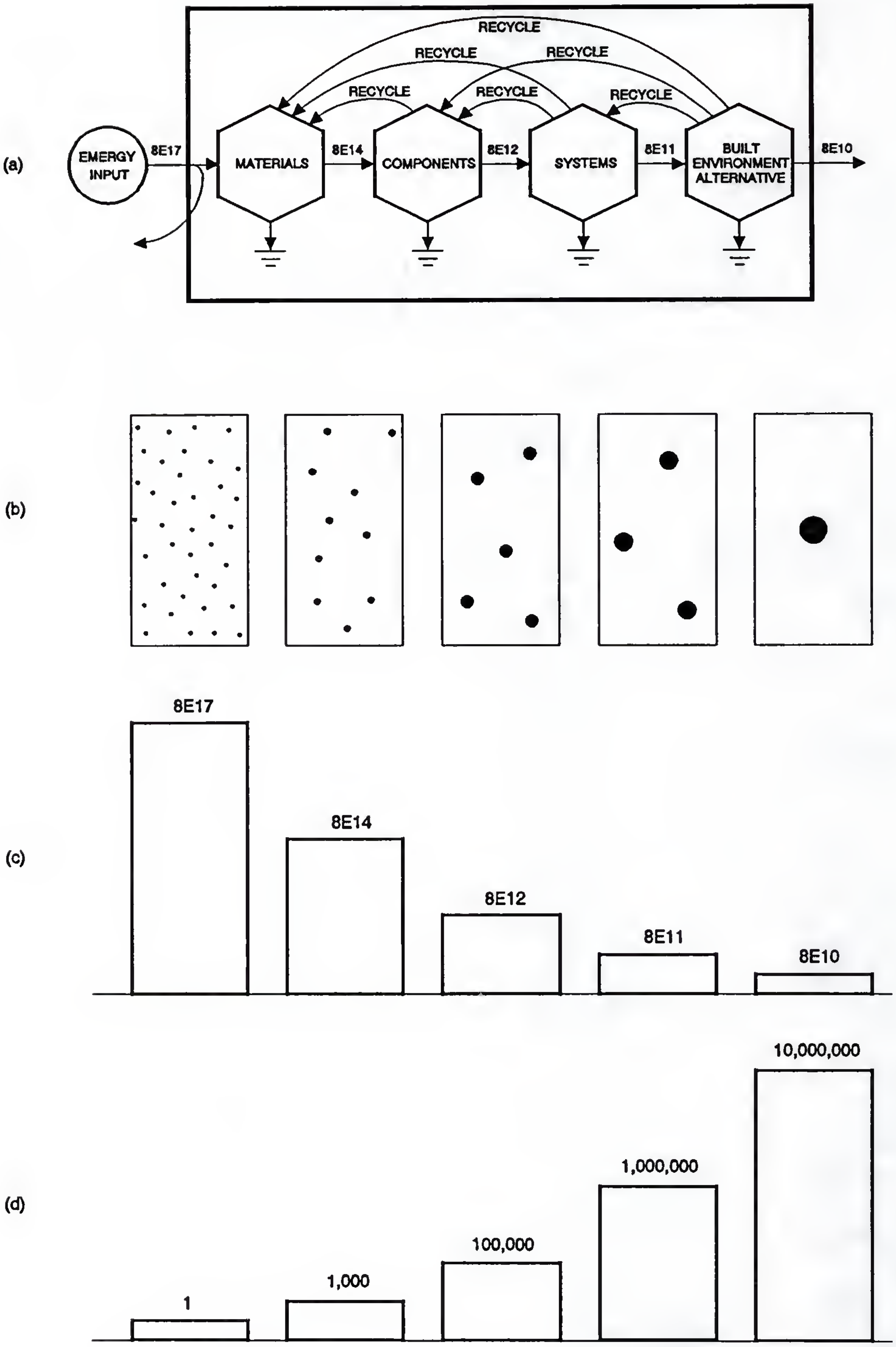

(a)
SOLAR
6E6
PRODUCERS
6,000
PPRIMARY CONSUMERS
600
SECONDARY CONSUMERS
60
TERTIARY CONSUMERS
6
FEEDBACK
FEEDBACK
FEEDBACK
(b)
(c)
6E9
6E7
6E6
6E5
6E4
(d)
1
100
1,000
10,000
100,000

environment alternative EMERGY hierarchy also may be represented by a series of stepwise transformations from materials, to components, to systems, to a whole alternative (Figure 1-5). Miller (1980 in Odum, 1983) found development of land in Florida in an energy transformation hierarchy with an order of magnitude increase in EMERGY at each stage due to developer inputs of goods and services.

To account for total EMERGY of a built environment alternative through all 10 phases of environmental value engineering, a hierarchical organization designation system was developed. A review was made of two existing designation systems related to the built environment. First, the Construction Specification Institute's 16-division format, and second, the General Services Administration's UNIFORMAT Code of Accounts format.

The Construction Specifications Institute's 16-division format is used extensively by designers in the construction industry to document the specification requirements of the various materials, components, and systems to be used in a built environment alternative. The format is derived from the various activities that take place during the built environment alternative's construction phase. Before the 1940s, designs for buildings were transmitted from designer to constructor primarily by drawings (Simmons, 1985). Written specifications were not organized into a standard format until 1963. In 1963 the Construction Specifications Institute introduced the 16-division format in a publication called The

Figure 1-5. Built environment EMERGY hierarchy.
(a) EMERGY transformation diagram.
(b) Distribution of size and spatial pattern of units in each category.
(c) Graph of EMERGY flows at each phase in the EMERGY hierarchy.
(d) Solar transformities for each position in the hierarchy.


(a)
EMERGY INPUT
8E17
MATERIALS
8E14
COMPONENTS
8E12
SYSTEMS
8E11
BUILT ENVIRONMENT ALTERNATIVE
8E10
RECYCLE
RECYCLE
RECYCLE
RECYCLE
RECYCLE
RECYCLE
(b)
(c)
8E17
8E14
8E12
8E11
8E10
(d)
1
1,000
100,000
1,000,000
10,000,000

CSI Format for Construction Specifications (Simmons, 1985). The Construction Specifications Institute 16-division format divisions are:

1-General Requirements
2-Site Work
3-Concrete
4-Masonry
5-Metals
6-Wood and Plastics
7-Thermal and Moisture Protection
8-Doors, Windows, and Glass
9-Finishes
10-Specialties
11-Equipment
12-Furnishings
13-Special Construction
14-Conveying Systems
15-Mechanical Systems
16-Electrical Systems

The 16-division format was intended to standardize the subdivision of a built environment alternative into construction subcontractor work packages and provide a construction cost estimation format for these work packages. Utilization of the format to determine the unit cost of specific built environment alternative systems is very difficult. For example, an exterior wall system may have materials and components in division 4 (masonry), division 7 (thermal and moisture protection), division 5 (metals), and division 9 (finishes). Therefore, design decision makers interested in the unit costs need another designation system.

The General Services Administration developed the UNIFORMAT Code of Accounts system during the 1980s. With the UNIFORMAT Code of Accounts system, the systems of a built environment alternative are categorized into 12 code of account elements. These code of accounts elements are:

01-Foundations
02-Substructure
03-Superstructure
04-Exterior Closure
05-Roofing
06-Interior Construction
07-Conveying Systems
08-Mechanical
09-Electrical
10-General Conditions and Profit
11-Equipment
12-Site Work

These 12 code of account elements are subdivided into several levels of detail (General Services Administration, 1981). Appendix E provides the UNIFORMAT Code of Accounts through detail level 5. The General Service Administration requires cost estimates conducted by designers to be consolidated and submitted at detail level 3.

The UNIFORMAT Code of Accounts provides a designation system that enables design decision makers to separate built environment alternative costs by system. It is organized hierarchically and by built environment alternative system instead of the construction trade format of the Construction Specifications Institute's 16-division format. Johnson (1990) states that the UNIFORMAT structure is similar to the design decision process and therefore facilitates cost management as design progresses. Environmental value engineering incorporates the UNIFORMAT Code of Accounts structure and designation system to account for the EMERGY of environment, fuel energy, goods, and services inputs to be used through the 10 phases of environmental value engineering.

Case Study

For the application of environmental value engineering, exterior wall construction was selected, with evaluations to include two alternatives: concrete masonry units and concrete tilt-up panels. The Alert Shelter Complex at Homestead Air Force Base in Florida was selected for evaluation because a value engineering management report on the Alert Shelter Complex, conducted by Hanscomb Associates, Inc. (1986), proposed the use of a concrete tilt-up panels in place of designed concrete masonry walls.

The extent of the exterior wall construction system, consisting of approximately 19,200 square feet, is indicated on the Alert Shelter Complex floor plan (Figure 1-6). Included in the system area are portions of the exterior wall over the eight aircraft hangar doors.

Case study application alternatives A and B designate the exterior wall construction systems of concrete masonry units and concrete tilt-up panels, respectively. Wall sections of the exterior wall construction systems of alternatives A and B are provided in Figure 1-7. Referring to Figure 1-7, the pitched roof construction system for both alternatives is indicated because it is affected. The concrete masonry unit exterior wall construction system of alternative A supports the pitched roof construction system, whereas the pitched roof construction system of the concrete tilt-up panel exterior wall construction system of alternative B must be supported by steel columns and beams as proposed by the value engineering

Figure 1-6. Floor plan of case study application Alert Shelter Complex.

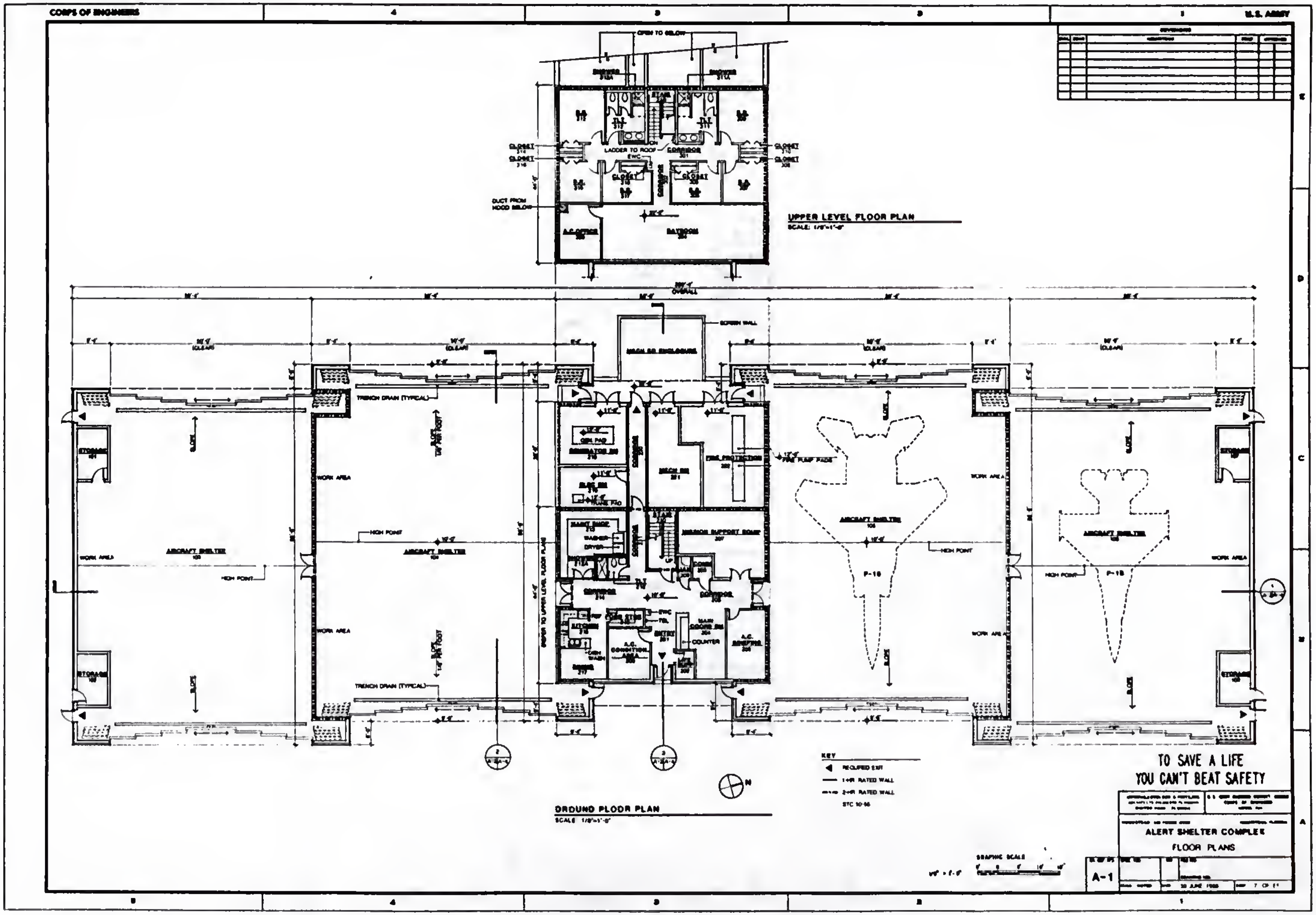
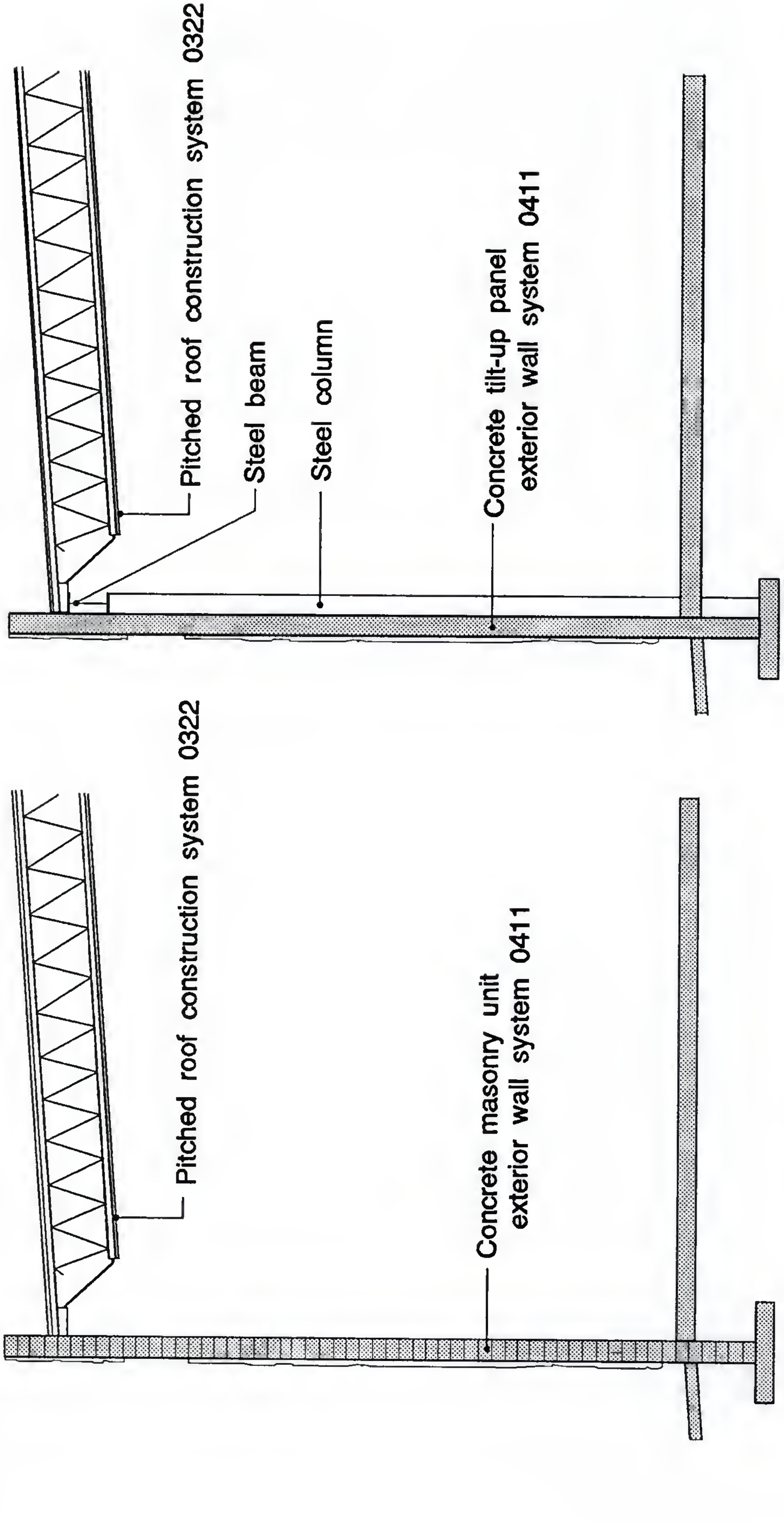

CORPS OF ENGINEERS
U.S. ARMY
UPPER LEVEL FLOOR PLAN
SCALE: 1/8"=1'-0"
OPEN TO BELOW
LADDER TO ROOF
CORRIDOR
301
EWC
CLOSET
DUCT FROM
HOOD BELOW
SCREEN WALL
OVERALL
(CLEAR)
TRENCH DRAIN (TYPICAL)
WORK AREA
HIGH POINT
AIRCRAFT SHELTER
STORAGE
SLOPE
GEN PAD
WASHER
DRYER
STAIR
UP
EWC
TEL
COUNTER
ENTRY
201
FIRE PUMP PADS
F-15
RISER TO UPPER LEVEL FLOOR PLAN
GROUND FLOOR PLAN
SCALE 1/8"=1'-0"
KEY
REQUIRED EXIT
1-HR RATED WALL
2-HR RATED WALL
STC 10-85
TO SAVE A LIFE
YOU CAN'T BEAT SAFETY
ALERT SHELTER COMPLEX
FLOOR PLANS
GRAPHIC SCALE
A-1
30 JUNE 1988
7 OF 11

Figure 1-7. Exterior wall sections of case study application Alert Shelter Complex.
(a) Case Study Application Alternative A.
(b) Case Study Application Alternative B.


Pitched roof construction system 0322
Concrete masonry unit exterior wall system 0411
Pitched roof construction system 0322
Steel beam
Steel column
Concrete tilt-up panel exterior wall system 0411

(a)

(b)

management report by Hanscomb Associates, Inc. (1986). The pitched roof construction system must be included to properly evaluate the environmental impact of both exterior wall construction system alternatives.

Methods of analysis used on case study application alternatives A and B are described in Chapter 2 following a review of analysis systems related to environmental value engineering. Analysis results are presented in Chapter 3.

State-of-the-Art Review

An extensive literature search of related analysis systems was conducted. A literature codeword search of Dissertation Abstracts International (CD-ROM), National Technical Information Service (CD-ROM), U. S. Government Publications (CD-ROM), UN Publications (CD-ROM), the Energy Index, and the Environmental Index found no prior use of the term "environmental value engineering".

Benefit-to-Cost Analysis

Benefit-to-cost analysis is a systematic method of identifying and measuring the economic benefits and costs of a project or program (Hufschmidt, James, Meister, Bower, & Dixon, 1983). Benefit-to-cost analysis became widely used in the United States following passage of the federal government's Flood Control Act of 1936, which required water-resource project benefits to exceed the estimated costs (Collier & Ledbetter, 1982). According to Hufschmidt et al. (1983), the benefits of a project are the values of incremental outputs of goods and services including environmental services made possible by the project, and the costs are the values of the incremental real resources used by the project. Monetary value is the basis of comparison used in benefit-to-cost analysis. Project costs and benefits must be discounted over time to compensate for monetary value fluctuations.

Benefit-to-cost analysis compares the benefit-to-cost ratio (BCR) of a proposed project. Collier and Ledbetter (1982) present a simplified, conventional model for the benefit-to-cost ratio given in equation 1:

$$\text{Conventional BCR} = \frac{\text{Net savings to user}}{\text{Owner's net capital cost + Owner's net operating and maintenance cost}} \qquad (1)$$

The owner's net capital cost reflects the equivalent annual costs obtained by application of the appropriate present worth factor, which is based on a specific "expected life" or "study period" and interest rate. Standard methods of benefit-to-cost analysis are presented in the American Society for Testing and Materials standard E964 (American Society for Testing and Materials, 1990).

Results of a benefit-to-cost analysis using benefit-to-cost ratios (BCR) indicate the ratio of benefit dollars for every dollar invested as cost. A BCR less than 1.0 indicates a project that is uneconomical, while a BCR greater than 1.0 indicates a project whose benefits or savings exceed its costs and is therefore economic over a specified period of time.

Where project costs and benefits are easily determined, the application of benefit-to-cost analysis is simple and straightforward. Benefit-to-cost analysis is normally applied to the economic evaluation of buildings and building systems. Extension of benefit-to-cost analysis to evaluate environmental quality and quantify the environmental impact of development projects is proposed by Hufschmidt et al. (1983).

Differences between benefit-to-cost analysis and environmental value engineering include the following:

1. Benefits and costs are considered for a limited study period.
2. Study period is only a portion of the use phase of environmental value engineering.
3. Benefits and costs are measured in dollars.
4. Environmental inputs are not considered.
5. Costs are not totalled over the life cycle of a project.

Environmental value engineering is a long-term analysis system that considers all built environment alternative external source inputs and benefits (savings) in terms of EMERGY, whereas benefit-to-cost analysis is a short-term analysis system in terms of dollars that considers a limited amount of built environment alternative costs and benefits and excludes environmental source inputs. Benefit-to-cost only measures the part of benefit and cost due to people's participation. Since money is not paid to nature, its benefits or losses are not evaluated and cannot be evaluated with money that is paid to people.

Embodied Energy

Many documents have been written on embodied energy since the energy crisis of the mid-1970s. Embodied energy is a general term that refers to several different kinds of energy analysis. One of these is process analysis (availability analysis-EXERGY) that evaluates mechanical and chemical energy used (including Gibbs free energy). Another is input-output energy analysis. Input-output energy analysis is used to estimate services and process analysis for fuel, electricity, and chemical energy. The Center for Advanced Computation (CAC), now called the Energy Research Group of the University of Illinois, and The Stein Partnership (TSP), under contract to the United States Department of Energy, developed input-output energy analysis and produced two documents on the embodied energy of building construction using input-output energy analysis. These documents are Energy Use for Building Construction, Final Report (Hannon, Stein, Segal, & Serber, 1976) and Energy Use for Building Construction, Supplement (Hannon, Stein, Segal, Deibert, Buckley, & Nathan, 1977). A United States Department of Energy (1981) document prepared by the Stein Partnership provides fuel energy inputs in BTUs per unit of building material or component delivered to the jobsite. Fuel energy inputs are included for the extraction of raw materials, the processing and manufacturing of finished materials and components, transportation, the prorated share of processing plants and equipment, and other overhead items required for the industries that produce building materials and their components. For a comparison of concepts of embodied energy, see Odum (1983).

Hannon, Stein, Segal, and Serber (1978) evaluate energy and labor in the construction sector based on an energy and employment input-output model of the construction industry. Roose (1978) edited a book that contains information on embodied energy related to various building materials. Another source by Stein, Reynolds, and McGuinness (1986) contains information about embodied energy, with references to Hannon, Stein, Segal, and Serber (1977). Zimmerman and Hart (1982) include information on the energy intensiveness of typical building materials with a reference to Roose (1978). Leonov and Stenhouse (1979) discuss the use of embodied energy in building equipment and construction materials with a reference to Hannon, Stein, Segal, and Serber (1976). A recent paper by Lawson (1992) describes the use of capital energy costs in life cycle energy costing. The capital energy costs given by Lawson are comparable to those of Hannon, Stein, Segal, and Serber (1978).

All of these documents lack consideration of environment, goods, and services inputs that go into built environment equipment, materials, and construction because only fuel energy inputs were considered. The energy value differences between EMERGY and embodied energy, as described in the previous documents, are significant. Comparison of EMERGY and embodied energy for various materials is provided in Appendix

A, based on EMERGY data from Appendix D, and embodied energy data from Hannon et al. (1978).

Differences between the comparison of built environment alternatives using embodied energy, as described in the previous documents, and environmental value engineering, which is based on EMERGY, are even more significant because the embodied energy data do not include all of the life cycle phases, which are described in the environmental value engineering phases of life cycle section of this dissertation. These differences are what make the environmental value engineering analysis system unique.

EMERGY Analysis

The most significant difference between environmental value engineering and other analysis systems is that it utilizes EMERGY analysis techniques developed by Howard T. Odum. EMERGY is a scientific-based measure of wealth that puts raw materials, commodities, goods, and services on a common basis, the energy of one type required to generate that item (Odum, 1991). Although EMERGY analysis was developed for all inputs, much of the application so far has been to ecological and resource systems. Here the measure is extended to environmental value engineering to analyze the environmental contributions and requirements of built environment alternatives.

EMERGY analysis techniques include system diagramming with an "energy systems language" that has been developed over the past three decades. Another aspect of EMERGY analysis utilized is the use of energy and, more specifically, "EMERGY" as a basis of comparison instead of money. Conversion from EMERGY to money can be made using EMERGY analysis techniques. Energy and money flow in opposite directions (Odum & Odum, 1981). Money is paid only to people for the labor to produce goods and services and is not paid to the earth's environment for use of the natural resources which went into the goods and services. The units of EMERGY utilized in environmental value engineering are solar emjoules (sej) because EMERGY evaluation traces what was required for a product back to a common form of energy to show how energy requirements for different products compare (Odum, 1991).

The EMERGY analysis approach evaluates a resource with physical measures and then calculates the macroeconomic dollars of the public economy's buying power contributed by that resource (Odum, in press). Human efforts and environmental efforts are evaluated on a common basis. Odum provides a detailed review of the historical background of EMERGY analysis, related concepts, and methods.

EMERGY analysis includes the following methods (Odum, 1991):

1. Draw a detailed energy systems diagram.
2. Draw an aggregated energy systems diagram.
3. Set up an EMERGY analysis table to calculate EMERGY of main sources and contributions of the system being analyzed.
4. Calculate EMERGY indices from the EMERGY analysis

table.

5. Write a simulation program to study the system through time.
6. Evaluate alternatives to maximize EMERGY contributions to the unified economy of humanity and nature for recommending public policies.

Results of an EMERGY analysis are in the form of EMERGY analysis tables and simulation outputs. The EMERGY analysis tables calculate macroeconomic United States dollar contributions of each input source using equation 2.

$$\frac{\text{(Source unit quantity)(Transformity in solar emjoules)}}{\text{Solar EMERGY per US dollar for a specified year}} \tag{2}$$

Evaluations of sources are made to determine which contribute the most EMERGY to the system being analyzed. Recommendations are made based on these EMERGY contributions to the system. EMERGY analysis applications serve to set values for natural resources and ecosystem processes. Environmental contributions to the economy are evaluated.

The following are aspects of EMERGY analysis incorporated in environmental value engineering:

1. use of energy systems diagrams and language,
2. solar emjoules (sej) as basis of EMERGY calculations,
3. use of EMERGY analysis tables,
4. Environmental value engineering EMERGY indices based on EMERGY analysis EMERGY indices,

5. use of a computer simulation program, and
6. utilization of the macroeconomic United States dollar contributions for services (labor), based on Solar EMERGY of 2.0E12 solar emjoules (sej) per U.S. dollar in 1990 (Appendix D).

Innovations in environmental value engineering follow:

1. Environmental value engineering uses EMERGY on built environment alternatives.
2. A simulation program is written to simulate multiple built environment alternatives simultaneously.
3. Environmental value engineering totals EMERGY of built environment alternatives through 10 environmental value engineering phases.

EMERGY analysis and environmental value engineering account for environmental contributions made to systems. EMERGY analysis forms the main basis of environmental value engineering. Therefore, as refinements are made to the EMERGY analysis system, they would be incorporated in environmental value engineering.

Life Cycle Cost Analysis

Life cycle cost (LCC) analysis can be defined as an economic assessment of competing design alternatives, considering all significant costs over the economic life of each alternative, expressed in equivalent dollars (Dell'Isola & Kirk, 1981; Kirk & Spreckelmeyer, 1988). The analysis period, study period, or economic life cycle period of LCC normally is between 25 and 40 years (Kirk & Spreckelmeyer, 1988). The LCC analysis method sums, in either present-value or annual-value terms, all relevant building or building system costs over a designated analysis or life cycle period.

The LCC of a building or building system is calculated by summing all relevant cash flows, which are discounted to a common point in time, through a designated analysis period. Life cycle cost analysis may be applied at any time during a project's development or use. The standard practice for measuring life cycle costs of buildings and building systems is provided in the American Society for Testing and Materials standard E917 (American Society for Testing and Materials, 1990). Computation of an LCC in present-value (PVLCC) terms is represented by equation 3, which is given in the American Society for Testing and Materials standard E917.

$$PVLCC = \sum_{t=0}^{N} \frac{C_t}{(1+i)^t} \qquad (3)$$

where

C_t = the sum of all relevant costs occurring in year t,

N = length of study period (years), and

i = the discount rate.

Life cycle costs include the following: initial investment, operating costs, maintenance, utilities, repair, replacement, taxes, insurance, financing, and salvage/terminal (American Society for Testing and Materials, 1990; Kirk & Spreckelmeyer, 1988). Discount formulas are utilized in LCC analysis to determine the present value of various relevant future costs. Future costs include replacement costs of building components or systems having a shorter life than the LCC analysis period. The LCC analysis total present-value or worth of several alternatives, which satisfy the same functional requirements, are compared to determine which alternative has the lowest total LCC.

Life cycle analysis is performed if the alternatives being considered have different relevant costs over the analysis period. If there are no relevant cost differences between alternatives, economic decision making is based on initial costs.

Several aspects of LCC analysis are incorporated in environmental value engineering because of their use in the value engineering analysis system, which is described in the following section. These aspects include:

1. inclusion of all relevant costs (inputs),
2. summation of all relevant costs,
3. calculation of initial costs and total LCC, and
4. multiple alternative comparison.

Significant differences exist between LCC and environmental value engineering. These differences are:

1. The LCC has a limited analysis period versus 10 environmental value engineering life cycle phases.
2. Relevant LCC costs do not include environmental inputs and impacts.
3. The LCC uses a monetary basis, whereas environmental

value engineering uses an EMERGY basis.

The concluding statement in David S. Haviland's text on life cycle cost analysis states, "As owners and architects alike respond to a world of increasingly limited resources (be they dollars, mineral deposits or kilowatt hours), the life cycle cost analysis tool will become increasingly valuable and perhaps even indispensable in helping to make critical resource decisions" (Haviland, 1978, p. 77).

When economic growth has leveled and is in descent, money cannot be counted on to increase its value through investment, but will decline as the level of real wealth declines. This would negate the use of life cycle cost analysis.

Value Engineering

Zimmerman and Hart (1982) have defined value engineering as a proven management technique using a systematized approach to seek out the best functional balance between the cost, reliability, and performance of a product or project. A formal "job plan" forms the systematic approach to value engineering. The job plan involves each of the disciplines associated with the product or project through a team approach to value engineering. According to Zimmerman and Hart (1982), the job plan consists of the following five basic steps:

1. Information Phase
2. Creative Phase
3. Judgment Phase
4. Development Phase
5. Recommendation Phase

The information phase of a value engineering job plan involves obtaining as much information as possible about product or project design requirements, design constraints, and costs related to the product or project. Design and design constraint information is obtained from the owner and designer. Cost information is obtained from the designer and includes initial construction cost and costs of ownership and operation. Functional analysis is utilized during the information phase to determine product or project functions and their associated costs.

The creative phase of a value engineering job plan may also be called the speculation or brainstorming phase. During this phase a number of alternatives, which provide the same basic functions, are proposed without regard to the alternative's practicality. Advantages and disadvantages of each alternative are considered but not judged. Judgment decisions take place during the next job plan phase.

The judgment phase of a value engineering job plan is used to analyze, critique, and rank each of the alternatives proposed during the creative phase. The functions of each alternative are evaluated and prioritized according to weighted values, which are based on tangible and nontangible functions of the alternative. The alternatives that offer the greatest cost savings potential are determined. These alternatives are then developed during the next job plan phase.

The development phase of a value engineering job plan selects the alternatives determined to have the greatest cost savings potential and develops them into workable solutions. Comparisons are made between the original alternatives and the proposed alternatives. The value engineering team must assure that proposed alternatives are workable and reliable and that they can be implemented. Other implications that must be considered in making proposed alternative recommendations are cost and scheduling. Life cycle cost analysis is conducted on the original and proposed alternatives to predict initial, operating, and maintenance costs over a specific study period. Factors such as life cycle costs, aesthetics, performance, energy consumption, and "buy American" are compared for each alternative utilizing matrix evaluation techniques. Recommendation of proposed alternatives are then made.

The recommendation phase is the last step of the value engineering job plan. Value engineering team recommendations are presented to the decision makers for review, adoption, and implementation of the proposed alternatives that are selected. Salesmanship is a keyword during this phase. The value engineering team must make good recommendations, which are based on an open-minded review of all alternatives, to reduce unnecessary costs to the product or project owner. Monetary cost reduction is the main objective of value engineering.

Aspects of traditional value engineering are modified for inclusion in environmental value engineering. Traditional value engineering includes LCC analysis for a set study period of time. The LCC analysis methodology detailed in ASTM E917-89 defines "study period" as follows:

> The study period appropriate to the LCC analysis may or may not reflect the life of the building or system to be evaluated.
> (American Society for Testing and Materials, 1989, p. 12)

To account for the true or total environmental impact inputs of built environment alternatives, the study period must include all phases of the built environment alternatives. This is a distinct difference between EVE and traditional value engineering. Figure 1-3 indicates the phases included in EVE and that EVE analyzes the total environmental impact of whole built environment alternatives versus only specific component comparisons as conducted by value engineering.

It may be concluded from the state-of-the-art review that available systems for analyzing built environment alternatives do not adequately evaluate environment or resource contributions. As the effects of environmental impacts related to the expansion and modification of the built environment increase, so does the potential need for an analysis system like environmental value engineering.

CHAPTER 2
METHODS

This chapter represents methods utilized to develop the environmental value engineering analysis system and its application to a case study.

Energy Systems Diagrams and Language

Energy systems diagrams (models) and language are used in this dissertation to communicate the relationship of EMERGY to a built environment alternative's systems. Dr. Howard T. Odum has been developing the energy diagrams and language used in EMERGY analysis for more than three decades. This section of the dissertation describes energy system diagrams and language. For a complete description of energy system diagrams and language development, see Odum (1971, 1983, and 1991) and Odum & Odum (1981).

Descriptions of energy systems diagram symbols and language are aggregated according to natural groupings and hierarchies (Appendix C). Energy systems diagrams are based on the fact that: 1) some energy flows on all pathways, 2) some energy is transformed through production, consumption and storage processes, and 3) energy quality is increased through transformation of energy. This energy flow is measured in terms of its EMERGY content.

There is an EMERGY hierarchical organization to energy systems diagrams. External to the energy system boundary are energy sources, which are arranged from lowest quality in the lower left corner, then clockwise to the highest quality source in the lower right corner. The bottom of the energy system diagram boundary is used only for the dispersion of potential energy into heat, which is indicated by a heat sink symbol. Within the energy system boundary are producers, consumers, and storages which ascend in energy quality from left toward the right. Relationships between these producers, consumers, and storages are indicated by energy circuits or pathways of energy flow.

The energy systems diagram and language were used to visually represent the influences and relationships of the various external EMERGY input sources to a built environment alternative. Two levels of energy systems diagrams were constructed to represent these relationships. First, a detailed energy systems diagram of a typical built environment alternative system was drawn with its corresponding EMERGY input sources. Second, an aggregated energy systems diagram was drawn to indicate the relationship of EMERGY of all systems of a built environment alternative through all 10 environmental value engineering phases.

Detailed EMERGY Input Diagram

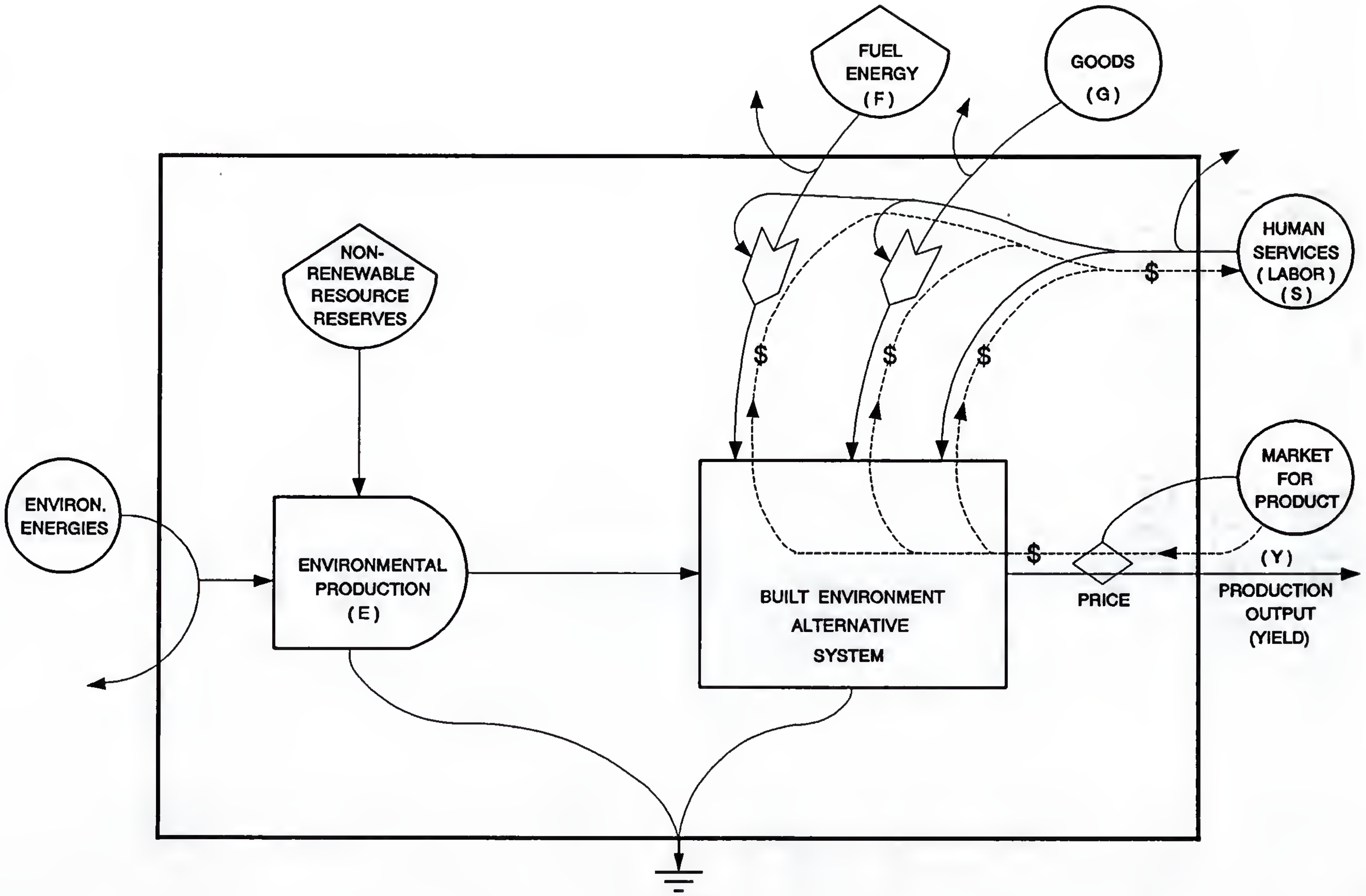
The purposes of a detailed EMERGY diagram are to provide an overview of the relevant influences affecting the EMERGY of built environment alternative systems and to organize EMERGY data collection. The detailed EMERGY diagram is like an inventory of input sources. Figure 2-1 is a detailed EMERGY diagram of a typical built environment alternative system.

The following steps are taken to diagram a typical built environment alternative system:

1. The system boundary is defined.
2. A list of EMERGY input sources is made.
3. Input sources are arranged in order of energy quality outside the system boundary.
4. Pathway lines are drawn to represent EMERGY flows.
5. The system production output pathway line is drawn.

The detailed EMERGY diagram represents the EMERGY related to environment (E), fuel energy (F), goods (G), and services (S) inputs utilized in a built environment alternative system. Each of these sources may be considered as a limiting factor that affects the availability of the built environment alternative system. Representation of the total environmental impact EMERGY of all built environment alternative systems for an environmental value engineering phase are similar to that of an individual system. The next higher level of detail to be diagrammed was an aggregated EMERGY diagram, which indicates the relationship of all of the environmental value engineering phases of a built environment alternative to the various source inputs. The aggregated EMERGY diagram represents the cumulative total environmental impact EMERGY of all systems of a built environment alternative through the 10 phases of environmental value engineering.

Figure 2-1. Detailed EMERGY diagram.


FUEL ENERGY (F)
GOODS (G)
NON-RENEWABLE RESOURCE RESERVES
HUMAN SERVICES (LABOR) (S)
$
$
$
$
MARKET FOR PRODUCT
ENVIRON. ENERGIES
ENVIRONMENTAL PRODUCTION (E)
$
(Y)
BUILT ENVIRONMENT ALTERNATIVE SYSTEM
PRICE
PRODUCTION OUTPUT (YIELD)

Aggregated EMERGY Input Diagram

An aggregated EMERGY diagram was drawn to represent the total source inputs of EMERGY from environment (E), fuel energy (F), goods (G), and services (S) inputs for a whole built environment alternative over the 10 environmental value engineering phases. Figure 2-2 is an aggregated EMERGY diagram indicating EMERGY inputs through these phases and production output transformity for a built environment alternative.

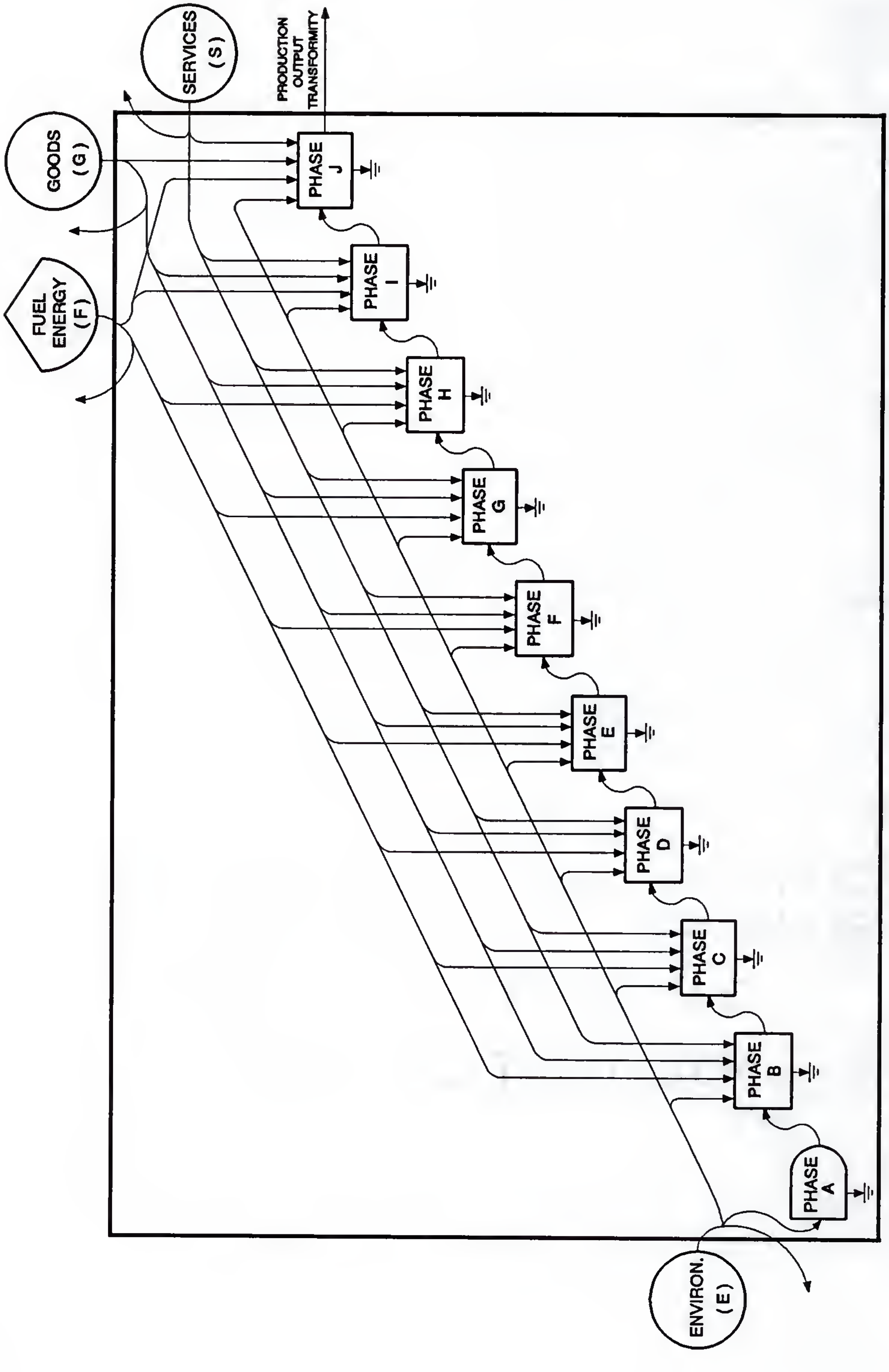
Components within the aggregated EMERGY diagram boundary represent EMERGY accumulations that occur within each environmental value engineering phase. EMERGY pathways are indicated from the various external input sources to the built environment alternative as it passes through the 10 environmental value engineering phases. The circulation of money is not indicated because environmental value engineering considers environmental impacts in terms of EMERGY and not money. Any external input sources involving money are converted to EMERGY using the appropriate transformity of the input source.

Environmental value engineering EMERGY calculations are conducted by use of EMERGY analysis tables and an EMERGY simulation program. Methods of EMERGY analysis table preparation and EMERGY simulation input are described in the following sections.

Environmental Value Engineering EMERGY Analysis Tables

An environmental value engineering EMERGY analysis table, in conjunction with a simulation program, is used to

Figure 2-2. Aggregated EMERGY diagram.


SERVICES (S)
GOODS (G)
FUEL ENERGY (F)
ENVIRON. (E)
PRODUCTION OUTPUT TRANSFORMITY
PHASE A
PHASE B
PHASE C
PHASE D
PHASE E
PHASE F
PHASE G
PHASE H
PHASE I
PHASE J

facilitate the calculation of EMERGY for the various sources of external input to a built environment alternative over the 10 environmental value engineering phases.

Procedures for making an environmental value engineering EMERGY analysis table are similar to those of an EMERGY analysis table as designed by Dr. Howard T. Odum, except for a few differences. One difference is that the external input sources are consolidated into environment, nonrenewable fuel energy, goods, and services. Another difference is that the environmental value engineering EMERGY analysis table account for all systems of a built environment alternative through the 10 phases of environmental value engineering. Table 2-1 is an environmental value engineering EMERGY analysis table. The procedures for making an environmental value engineering EMERGY analysis table are:

1. Make an environmental value engineering EMERGY analysis table for each built environment alternative system and each environmental value engineering phase with one line in the table for each environment, nonrenewable fuel energy, goods, and services input.
2. Number the lines to match back-up sheets for data sources, references, calculations, or other details.
3. Put the input source in the item column.
4. In the second column of data put the raw data for each item in grams, Joules, or dollars.
5. Put the appropriate solar transformity in the next column. Transformities are given in Appendix D.

Table 2-1. ENVIRONMENTAL VALUE ENGINEERING EMERGY ANALYSIS TABLE.

[EVE designation]

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			
E1	Atmosphere			
E2	Ecol. Prod.			
E3	Energy			
E4	Land			
E5	Water			
F	FUEL ENERGY			
F1	Equipment			
F2	Facilities			
G	GOODS			
G1	Equipment			
G2	Facilities			
G3	Materials			
G4	Tools			
S	Services			
S1	Labor			
S2	Labor			

6. In the fourth column, multiply data from column 2 by the solar transformity from column 3, thus obtaining solar EMERGY values.
7. Input the solar EMERGY values for each phase of each built environment alternative into the simulation program.

Solar transformities are obtained from research data as described in the EMERGY analysis section of the state-of-the-art review in Chapter 1. Appendix D provides typical solar transformities related to the built environment.

Total EMERGY of a built environment alternative through the 10 environmental value engineering phases is calculated by the simulation program. From the environmental value engineering EMERGY analysis tables and simulation program, environmental value engineering EMERGY indices are calculated to compare built environment alternatives, identify high EMERGY items, predict trends, and suggest which built environment alternative has the least environmental impact EMERGY over its life cycle.

Environmental Value Engineering EMERGY Indices

Environmental value engineering EMERGY indices were developed to compare various environmental impact EMERGY aspects of built environment alternatives. From these comparisons, trends can be predicted and suggestions related to built environment alternative selection can be made.

The main objective of environmental value engineering is to provide an analysis system for the selection of built environment alternatives that satisfy functional requirements with the least amount of environmental impact EMERGY. Environmental value engineering EMERGY indices form the basis of the environmental value engineering selection process. Environmental value engineering EMERGY indices can be used to determine if a built environment alternative has a net EMERGY yield. In other words, the total production output (yield) EMERGY exceeds the total source input EMERGY.

Environmental value engineering EMERGY indices are derived from EMERGY analysis EMERGY indices. EMERGY analysis EMERGY indices include solar transformity, net EMERGY yield ratio, and EMERGY investment ratio (Odum, 1991). EMERGY analysis EMERGY indices are calculated using data obtained from EMERGY Analysis tables. Environmental value engineering EMERGY indices are calculated from detailed and aggregated EMERGY input source data tables and simulation program tabular output data.

Environmental value engineering EMERGY indices are useful for comparing built environment alternatives. These indices include the following:

Solar transformity of an object or resource is the equivalent solar energy that would be required to generate (create) a unit of that object or resource efficiently and rapidly (Odum, 1991).

Net EMERGY yield ratio is the EMERGY of production output (yield) divided by the EMERGY of those inputs to the process that are fed back from the economy. This ratio indicates whether the process can compete in supplying a primary energy source for an economy (Odum, 1991).

$$\text{Net EMERGY yield ratio} = \frac{Y}{F + G + S} \qquad (4)$$

where

Y = production output (yield),
F = fuel energy input,
G = goods input, and
S = services (labor) input.

EMERGY investment ratio is the ratio of the EMERGY fed back from the economy to the EMERGY inputs from the free environment. This ratio indicates if the process is economical as a utilizer of the economy's investments in comparison to alternatives (Odum, 1991). Areas with higher investment ratios than average have more impact on the environment (Odum, 1981).

$$\text{EMERGY investment ratio} = \frac{F + G + S}{E} \qquad (5)$$

where

E = environmental input,
F = fuel energy input,
G = goods input, and
S = services (labor) input.

EMERGY per unit of built environment alternative is a measure of EMERGY concentration.

EMERGY per unit of built environment production output is a measure of the total EMERGY used by a built environment alternative from all sources divided by the total gross production output. This is the transformity per unit of built environment alternative production output.

Interpretation of the environmental value engineering EMERGY indices form the summary of an environmental value engineering analysis of built environment alternatives. Built environment alternative selection recommendations, which reduce environmental impact EMERGY, are based on these indices.

Environmental Value Engineering Simulation Program

Program Development

A computer simulation program was developed to study the EMERGY properties of aggregated energy systems diagram models of built environment alternatives over the 10 environmental value engineering phases. The program is used in conjunction with environmental value engineering EMERGY analysis tables to account for the total EMERGY of these built environment alternatives through their life cycle. Environmental value engineering EMERGY analysis table evaluation and simulations were used to compare the total EMERGY of various built environment alternatives.

DYNAMO was selected as the computer simulation program language for several reasons. First, DYNAMO is a computer simulation language (Richardson & Pugh, 1981). Second, simultaneous simulation of the EMERGY of multiple built environment alternatives are possible. Third, EMERGY calculation data can easily be input into the simulation program, and, finally, simulation output results are available in graphical and tabular formats. The environmental value engineering simulation program was developed to simulate up to 26 built environment alternatives simultaneously through 10 environmental value engineering phases.

The UNIFORMAT Code of Accounts designation system and 10 environmental value engineering phases were incorporated into the environmental value engineering simulation program through development of an EMERGY input variable designation system. The designation system was designed to accommodate the need for up to 26 built environment alternatives, additional environmental value engineering phases, and increased levels of detailed environmental value engineering EMERGY analysis. The DYNAMO simulation program used in environmental value engineering is provided in Appendix G. A description of the EMERGY input variable designation system utilized in the simulation program is provided in the following section on EMERGY calculations and program data input.

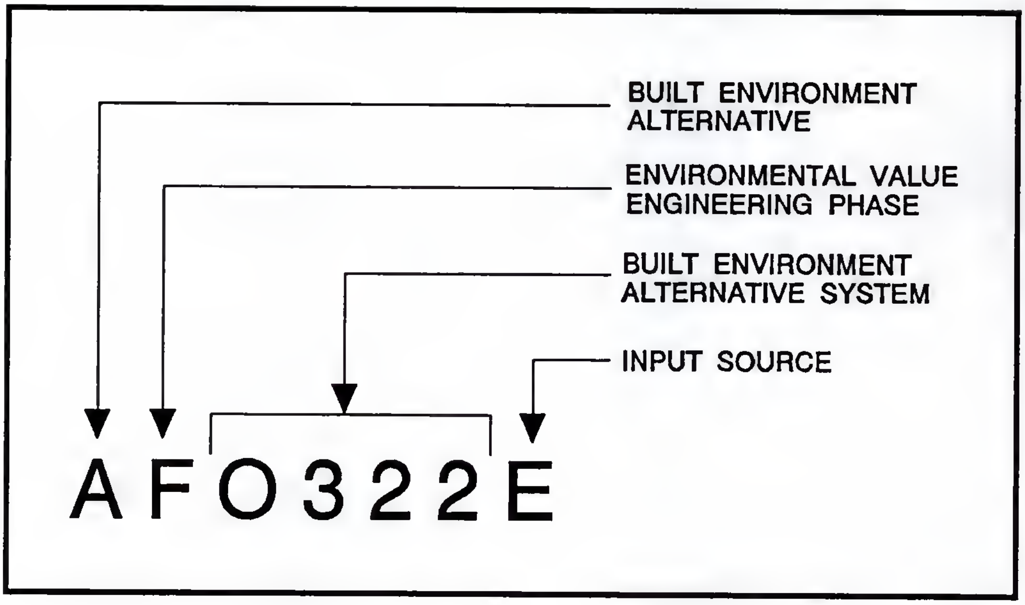
EMERGY Calculations and Program Data Input

Environmental value engineering analysis simulations are based upon EMERGY calculations and simulation program data input. A key element of EMERGY calculations and data input organization is the EMERGY input designation system developed specifically for environmental value engineering. A description of the environmental value engineering EMERGY input designation system is provided in Figure 2-3. The EMERGY input designation system was developed to match the various aspects of the environmental value engineering analysis system. These aspects include environmental impact EMERGY sources (Appendix B), environmental value engineering EMERGY analysis tables (Table 2-1), and the environmental value engineering simulation program (Appendix G).

Environmental value engineering EMERGY calculations and simulation program data input include the following steps:

1. Conduct material mass quantity take-off for initial environmental impact EMERGY of phases A-C for all alternatives and include as back-up sheets with the applicable environmental value engineering EMERGY analysis tables for material transformity phases A-C.
2. Enter material raw unit quantities for phases A-C directly into the simulation program.
3. Collect transformities for materials not in database and add to simulation program transformity list.
4. Construct environmental value engineering EMERGY analysis tables for alternatives and alternative systems being analyzed.
5. Categorize EMERGY inputs by environment (E), fuel energy (F), goods (G), and services (S).
6. Arrange environmental value engineering EMERGY analysis tables in order by alternative, phase, and alternative system.

Figure 2-3. Description of environmental value engineering designation system.


BUILT ENVIRONMENT ALTERNATIVE
ENVIRONMENTAL VALUE ENGINEERING PHASE
BUILT ENVIRONMENT ALTERNATIVE SYSTEM
INPUT SOURCE
A F O 3 2 2 E

7. Construct environmental value engineering EMERGY analysis table calculation back-up sheets for applicable alternative systems during environmental value engineering phases D-J.
8. Collect raw unit quantities of environment, fuel energy, goods, and services EMERGY source inputs on back-up sheets for inclusion in appropriate environmental value engineering EMERGY analysis tables.
9. Calculate source input EMERGY in environmental value engineering EMERGY analysis tables for each applicable alternative system during each environmental value engineering phase for all alternatives.
10. Transfer source input EMERGY quantities from environmental value engineering EMERGY analysis tables to the simulation program.
11. Check to make sure environmental value engineering EMERGY analysis table data were correctly input to the simulation program.

The following section provides a case study application of the environmental value engineering EMERGY calculations and data input methods described above.

Case Study Application Methods

Environmental value engineering was used to evaluate two alternative exterior wall construction systems and their corresponding pitched roof construction systems. These were

UNIFORMAT Code of Accounts systems 0322-Pitched Roof Construction and 0411-Exterior Wall Construction. Alternative A was the built environment alternative's concrete masonry unit exterior wall system 0411 as originally designed, and alternative B was the concrete tilt-up panel exterior wall system 0411 proposed by the Hanscomb (1986) value engineering study. Pitched roof construction system 0322 was included for both alternatives A and B because it was affected by the exterior wall construction system.

Environmental value engineering EMERGY analysis tables were used to calculate the environmental impact EMERGY related to these two systems through all 10 environmental value engineering phases. The EMERGY data was then input into the environmental value engineering simulation program for simulation of the two alternatives.

EMERGY Calculations and Program Data Input

To conduct the case study application EMERGY calculations, information was obtained from existing documents. These documents included architectural design drawings, architectural design budget, construction cost estimate, and Hanscomb (1986) value engineering study. Other EMERGY calculation information was obtained through references and interviews related to specific environmental value engineering phases. EMERGY calculation methods were applied to the case study application as follows:

1. Material mass quantity take-offs were conducted on design drawings for initial environmental impact

EMERGY of material transformity phases A-C for alternatives A and B.

2. Material raw unit quantities for phases A-C of both alternatives A and B were entered into the simulation program provided in Appendix G.
3. Applicable transformities were added to simulation program transformity list.
4. Environmental value engineering EMERGY analysis tables were constructed for each environmental value engineering phase of systems 0322 and 0411 for alternatives A and B.
5. Source input EMERGY was categorized as environment (E), fuel energy (F), goods (G), and services (S).
6. Environmental value engineering EMERGY analysis tables were arranged in order by alternative, phase, and alternative system.
7. EMERGY calculation back-up sheets were constructed for each source input of each environmental value engineering EMERGY analysis table for phases D-J.
8. Raw unit quantities of source inputs E, F, G, and S were calculated on back-up sheets for inclusion on appropriate environmental value engineering EMERGY analysis tables.
9. Source input EMERGY was calculated on each environmental value engineering EMERGY analysis table.
10. Source input EMERGY calculated on environmental value

engineering EMERGY analysis tables was input in the simulation program provided in Appendix G.

11. Simulation program input was checked against applicable environmental value engineering EMERGY analysis tables.

After all source input EMERGY quantities were input in the simulation program, a simulation of alternatives A and B was conducted. The methods of simulation are described in the following section.

Description and Use of Environmental Value Engineering Simulation Program

To perform the case study application simulation, certain simulation program variables were set. These variables included the analysis baseline year, environmental value engineering phase conclusion times, and simulation program specifications of computation interval delta time (DT), save period, plot period, and length of analysis period.

Once the simulation program variables were set, the simulation program was saved, compiled, simulated, viewed, and plotted. Results of the case study application simulation of EMERGY inputs are presented in the following chapter.

CHAPTER 3
RESULTS

This chapter presents the results obtained from an environmental value engineering analysis of case study application alternatives A and B. Environmental value engineering EMERGY analysis tables with calculation back-up sheets, environmental value engineering tabular simulation output, EMERGY input signatures, EMERGY input source data tables, and graphical simulation output are utilized to represent the analysis results. Results include case study application environmental value engineering calculations, detailed EMERGY input analysis, comparison of case study application systems, aggregated EMERGY input analysis, and comparison of case study application alternatives.

Case Study Application Environmental Value Engineering EMERGY Calculations

Application of methods described in the environmental value engineering case study application methods section of the previous chapter provides two basic types of results: 1) the completed environmental value engineering EMERGY analysis tables with applicable EMERGY calculation back-up sheets, which provide EMERGY input source data used in the detailed EMERGY input source data tables and simulation program; and 2) the tabular output of the simulation program. The tabular output provides input source data, which is used in the aggregated EMERGY input source data tables to be described later.

Environmental Value Engineering EMERGY Analysis Tables

Case study application environmental impact EMERGY quantities associated with input sources of environment, fuel energy, goods, and services are the result of calculations performed on the environmental value engineering EMERGY analysis tables and calculation back-up sheets provided in Appendix F. An example of an environmental value engineering EMERGY analysis table is provided in Table 3-1.

The EMERGY analysis tables and calculation back-up sheets are arranged in order by alternative, environmental value engineering phase, and alternative system. Figure 2-3 provides a description of the designation system used.

Information on the EMERGY analysis tables comes from three sources. First, the environmental impact EMERGY source items are from the list given in Appendix B. Second, raw units are obtained from the EMERGY analysis table calculation back-up sheets, which are described in the following section. Third, transformities are obtained from the transformity list provided in Appendix D. Environmental value engineering EMERGY analysis tables and calculation back-up sheets are provided for each system of each alternative for all environmental value engineering phases, even though specific EMERGY inputs may not occur. The input source solar EMERGY quantities

TABLE 3-1. EXAMPLE ENVIRONMENTAL VALUE ENGINEERING EMERGY ANALYSIS TABLE.

AF0411

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY			2.02E15
F1	Equipment	3.06E10 J	6.60E4	
F2	Facilities	NA		
G	GOODS			3.06E13
G1	Equipment	4.56E3 g	6.70E9	3.06E13
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICE			1.72E17
S1	Labor	8.59E4 $	2.00E12	1.72E17

calculated on the EMERGY analysis tables are then incorporated in the detailed EMERGY input source data tables and the simulation program.

EMERGY Analysis Table Calculation Back-up Sheets

The EMERGY analysis table calculation back-up sheets serve two purposes. First, they contain the raw unit calculations for input sources of environment, fuel energy, goods, and services associated with case study application alternatives A and B. These units are utilized in the EMERGY analysis tables to calculate the environmental impact solar EMERGY related to each system of each alternative for all environmental value engineering phases. Second, the back-up sheets contain raw data source citations.

An example portion of an EMERGY analysis table calculation back-up sheet for case study application alternative A designation AC0322 is provided in Figure 3-1. Appendix F contains the EMERGY analysis tables and corresponding calculation back-up sheets for case study application alternatives A and B.

Environmental Value Engineering Tabular Simulation Output

A tabular simulation output for the case study application was obtained as a result of an environmental value engineering simulation with the DYNAMO program. An example of tabular simulation output is provided in Table 3-2. It represents the environmental impact EMERGY of input sources of environment, fuel energy, goods, and services for phases of

Figure 3-1. An example of an environmental value engineering EMERGY analysis table calculation back-up sheet.

AC0322 EMERGY INPUT CALCULATION BACK-UP

Steel transformity = 1.80E9 sej/g
Petroleum product transformity = 6.60E4 sej/J
[Appendix D]
Steel quantity = 9.08E7 g [Material take-off]
Petroleum product quantity = (9.08E7 g)(2%) = 1.82E6 g
(1.82E6 g)/((9#/Gal)(55 Gal/BBL)(453.6 g/#))
(6.28E9 J/BBL) = 5.09E10 J

E. Environmental.
Steel
Environmental input transformity portion = 37.3 %
[Odum, in press]
(1.80E9 sej/g)(0.373) = 6.71E8 sej/g
(9.08E7 g)(6.71E8 sej/g) = 6.09E16 sej
Petroleum product
Environmental input transformity portion = 25 %
[Estimate]
(6.60E4 sej/J)(0.25) = 1.65E4 sej/J
(5.09E10 J)(1.65E4 sej/J) = 8.40E14 sej

Total environmental input = 6.17E16 sej

F. Fuel energy.
Steel
Fuel energy input transformity portion = 46.5 %
[Odum, in press]
(1.80E9 sej/g)(0.465) = 8.37E8 sej/g
(9.08E7 g)(8.37E8 sej/g) = 7.60E16 sej
Petroleum product
Fuel energy input transformity portion = 25 %
[Estimate]
(6.60E4 sej/J)(0.25) = 1.65E4 sej/J
(5.09E10 J)(1.65E4 sej/J) = 8.40E14 sej

Total fuel energy input = 7.68E16 sej

Table 3-2. EXAMPLE TABULAR SIMULATION OUTPUT.

```
TIME           2074.      2075.      2076.      2077.      2078

AA_C          370.e15    370.e15    370.e15    370.e15    370.e15
ADT         12.57e15   12.57e15   12.57e15   12.57e15   12.57e15
AET         34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT           210.e15    210.e15    210.e15    210.e15    210.e15
AGT                0.         0.         0.         0.         0.
AHT           13.8e15    13.8e15    13.8e15    13.8e15    13.8e15
AIT                0.         0.         0.         0.         0.
AJT         18.35e15   18.35e15   18.35e15   18.35e15   18.35e15
ATEIE         659.e15    659.e15    659.e15    659.e15    659.e15

BA_C        406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT         12.86e15   12.86e15   12.86e15   12.86e15   12.86e15
BET            32.e15     32.e15     32.e15     32.e15     32.e15
BFT         96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT         5385.e12   5385.e12   5385.e12   5385.e12   5385.e12
BHT         17.33e15   17.33e15   17.33e15   17.33e15   17.33e15
BIT                0.         0.         0.         0.         0.
BJT         20.29e15   20.29e15   20.29e15   20.29e15   20.29e15
BTEIE       590.8e15   590.8e15   590.8e15   590.8e15   590.8e15


TIME           2079.      2080.      2081.      2082.      2083.

A_C         370.e15    370.e15    370.e15    370.e15    370.e15
ADT         12.57e15   12.57e15   12.57e15   12.57e15   12.57e15
AET         34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT           210.e15    210.e15    210.e15    210.e15    210.e15
AGT                0.         0.         0.         0.         0.
AHT           13.8e15    13.8e15    13.8e15    13.8e15    13.8e15
AIT                0.         0.         0.         0.         0.
AJT         18.35e15   18.35e15   18.35e15   18.35e15   18.35e15
ATEIE         659.e15    659.e15    659.e15    659.e15    659.e15

BA_C        406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT         12.86e15   12.86e15   12.86e15   12.86e15   12.86e15
BET            32.e15     32.e15     32.e15     32.e15     32.e15
BFT         96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT         5385.e12   5385.e12   5385.e12   5385.e12   5385.e12
BHT         17.33e15   17.33e15   17.33e15   17.33e15   17.33e15
BIT                0.         0.         0.         0.         0.
BJT         20.29e15   20.29e15   20.29e15   20.29e15   20.29e15
BTEIE       590.8e15   590.8e15   590.8e15   590.8e15   590.8e15
```

alternatives A and B over the life cycle analysis period of 100 years. The complete output is provided in Appendix H.

Data for the case study application aggregated EMERGY input source data tables are obtained from the tabular simulation output. Designations for alternatives, environmental value engineering phases, input sources, and phase EMERGY totals are provided along the left side. The cumulative environmental impact EMERGY total is designated on the bottom line for each alternative. A description of case study application tabular simulation output use is provided in the section on aggregated EMERGY input source data tables.

Detailed EMERGY Input Analysis

The results of the detailed EMERGY input analysis portion of environmental value engineering for the pitched roof construction system 0322 of case study application alternatives A and B are represented first by detailed EMERGY input source data tables and then by translation of this data into detailed EMERGY input signatures.

Detailed EMERGY input source data tables represent EMERGY data calculation results from two sources. These sources are the environmental value engineering EMERGY analysis tables and the case study application simulation program tabular output.

Detailed EMERGY input signatures represent EMERGY input source data from the detailed EMERGY input source data tables. EMERGY input signatures are used in an environmental value engineering analysis to represent EMERGY quantities from multiple input sources.

The following four sections describe detailed EMERGY input source data table nomenclature, sources of EMERGY input data, and detailed EMERGY input signatures for the pitched roof construction system 0322 and exterior wall construction system 0411 of alternatives A and B.

Detailed EMERGY Input Source Data Tables for Pitched Roof Construction System 0322

The detailed EMERGY input source data tables for the pitched roof construction system 0322 of case study application alternatives A and B are given in Tables 3-3a and 3-3b. Referring to these tables, the system EMERGY input sources of environment (E), fuel energy (F), goods (G), and services (S) are given in columns below EMERGY input source data, and environmental value engineering phases are represented by rows along the left side. Phase EMERGY totals are given in the right column. Total EMERGY for the alternative system is given in the lower right corner of each EMERGY input source data table.

EMERGY input source data for columns (E), (F), (G), and (S) of the data table were obtained from the environmental value engineering EMERGY analysis tables of the designated alternative system for each environmental value engineering phase. These tables are provided in Appendix F. Phase EMERGY totals were obtained from the case study application simulation tabular output provided in Appendix H.

Table 3-3a represents the EMERGY input source data for the pitched roof construction system 0322 of case study

TABLE 3-3. DETAILED EMERGY INPUT SOURCE DATA FOR PITCHED ROOF CONSTRUCTION SYSTEM 0322.

(a) CASE STUDY APPLICATION ALTERNATIVE A.

EVE PHASE	EMERGY INPUT SOURCE DATA (SEJ)				TOTAL PHASE EMERGY
	ENVIRON. (E)	FUEL ENERGY (F)	GOODS (G)	SERVICES (S)	
A-C	6.17E16	7.68E16	6.56E15	2.16E16	1.67E17
D	1.41E13	1.48E14	0	4.56E15	4.72E15
E	0	2.75E15	3.35E15	2.40E16	3.01E16
F	0	6.49E15	1.01E15	2.84E16	3.59E16
G	0	0	0	0	0
H	0	3.21E16	4.76E15	5.56E16	9.25E16
I	0	0	0	0	0
J	1.21E12	6.46E14	3.67E13	1.33E15	2.01E15
TOTAL EMERGY OF ALTERNATIVE A SYSTEM 0322					3.32E17

(b) CASE STUDY APPLICATION ALTERNATIVE B.

EVE PHASE	EMERGY INPUT SOURCE DATA (SEJ)				TOTAL PHASE EMERGY
	ENVIRON. (E)	FUEL ENERGY (F)	GOODS (G)	SERVICES (S)	
A-C	6.46E16	8.03E16	6.86E15	2.26E16	1.74E17
D	1.44E13	1.50E14	0	4.64E15	4.80E15
E	0	3.30E15	3.50E15	2.52E16	3.20E16
F	0	6.67E15	1.10E15	2.96E16	3.74E16
G	0	0	0	0	0
H	0	3.21E16	4.76E15	5.56E16	9.25E16
I	0	0	0	0	0
J	1.27E12	6.73E14	3.84E13	1.39E15	2.10E15
TOTAL EMERGY OF ALTERNATIVE B SYSTEM 0322					3.43E17

application alternative A. Comments on the main aspects of Table 3-3a follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No environment input (E) at phases E, F, and H.
3. Goods input (G) at design phase D not included in analysis.
4. Environment input source (E) at design phase D includes land and water use.
5. No use phase G EMERGY input sources.
6. No recycling phase I EMERGY input sources because alternative A assumes no recycling.
7. Environment input source (E) at disposal phase J includes land use based on ratio of land surface area to debris volume for this system of alternative A. Refer to AJ0322 calculations in Appendix F.

Table 3-3b represents the EMERGY input source data for the pitched roof construction system 0322 of case study application alternative B. Comments on the main aspects of Table 3-3b follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No environment input (E) at phases E, F, and H.
3. Goods input (G) at design phase D not included in analysis.
4. Environment input source (E) at design phase D includes land and water use.

5. No use phase G EMERGY input sources.
6. No recycling phase I EMERGY input sources because alternative B assumes no recycling.
7. Environment input source (E) at disposal phase J includes land use based on ratio of land surface area to debris volume for this system of alternative B. Refer to BJ0322 calculations in Appendix F.

Detailed EMERGY input signatures were constructed to compare detailed input source EMERGY quantities for pitched roof construction system 0322 of case study application alternatives A and B.

Detailed EMERGY Input Signatures for Pitched Roof Construction System 0322

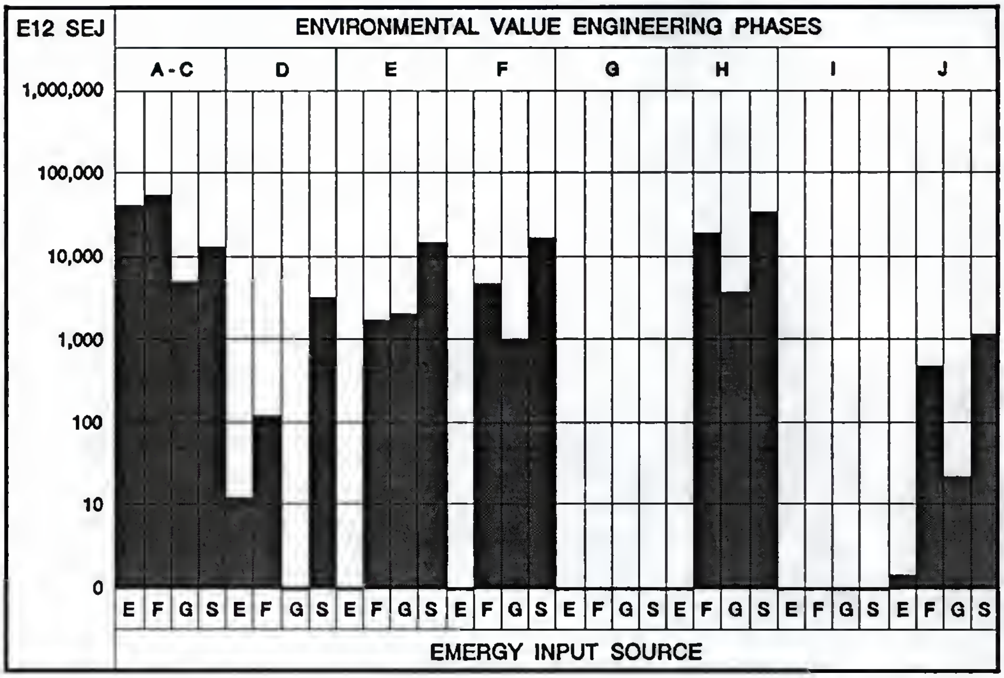
The detailed EMERGY input signature for the pitched roof construction system 0322 of case study application alternatives A and B are given in Figures 3-2a and 3-2b, respectively. Referring to these figures, the EMERGY input sources of environment (E), fuel energy (F), goods (G), and services (S) for each environmental value engineering phase are given in columns and are labeled along the signature bottom.

Quantities of input source EMERGY, in units of 10^{12} solar emjoules (sej), are represented along the left side of the signature. Each major quantity line represents an "order of magnitude" of 10 times.

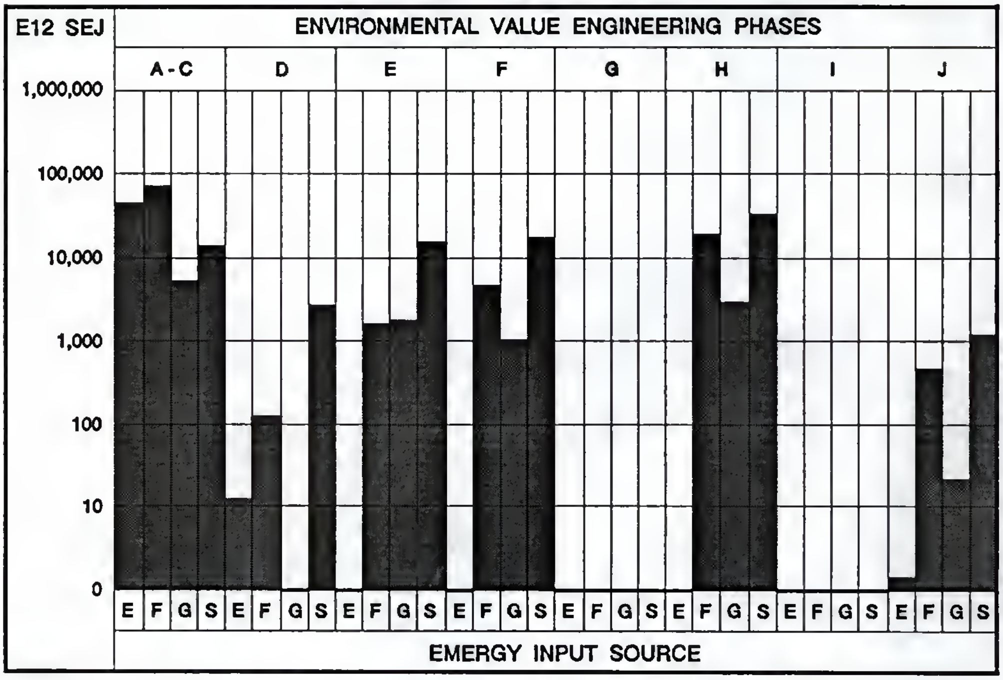
Environmental value engineering phase input source EMERGY quantities for columns (E), (F), (G), and (S) of Figures 3-2a

Figure 3-2. Detailed EMERGY input signatures of pitched roof construction system 0322.
(a) Case study application alternative A.
(b) Case study application alternative B.

(a)


E12 SEJ
ENVIRONMENTAL VALUE ENGINEERING PHASES
A - C
D
E
F
G
H
I
J
1,000,000
100,000
10,000
1,000
100
10
0
E F G S E F G S E F G S E F G S E F G S E F G S E F G S E F G S
EMERGY INPUT SOURCE

(b)


E12 SEJ
ENVIRONMENTAL VALUE ENGINEERING PHASES
A - C
D
E
F
G
H
I
J
1,000,000
100,000
10,000
1,000
100
10
0
E F G S E F G S E F G S E F G S E F G S E F G S E F G S E F G S
EMERGY INPUT SOURCE

and 3-2b were obtained from detailed EMERGY input source data Tables 3-3a and 3-3b, respectively.

Figure 3-2a represents the detailed EMERGY input signature for the pitched roof construction system 0322 of case study application alternative A. Comments on the main aspects of Figure 3-2a follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No environment input (E) at phases E, F, and H.
3. Goods input (G) at design phase D not included in analysis.
4. Environment input source (E) at design phase D includes land and water use.
5. No use phase G input sources.
6. No recycling phase I input sources because alternative A assumes no recycling.
7. Environment input source (E) at disposal phase J includes land use based on ratio of land surface area to debris volume for this system of alternative A. Refer to AJ0322 calculations in Appendix F.
8. Two highest phase EMERGY inputs occur at input sources of fuel energy (F), and environment (E) during material transformity phases A-C.
9. Third and fourth highest phase EMERGY inputs occur at input sources of services (S), and fuel energy (F) during demolition phase H.

Figure 3-2b represents the detailed EMERGY input signature for the pitched roof construction system 0322 of case study application alternative B. Comments on the main aspects of Figure 3-2b follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No environment input (E) at phases E, F, and H.
3. Goods input (G) at design phase D not included in analysis.
4. Environment input source (E) at design phase D includes land and water use.
5. No use phase G input sources.
6. No recycling phase I input sources because alternative B assumes no recycling.
7. Environment input source (E) at disposal phase J includes land use based on ratio of land surface area to debris volume for this system of alternative A. Refer to BJ0322 calculations in Appendix F.
8. Two highest phase EMERGY inputs occur at input sources of fuel energy (F), and environment (E) during material transformity phases A-C.
9. Third and fourth highest phase EMERGY inputs occur at input sources of services (S), and fuel energy (F) during demolition phase H.

Detailed EMERGY Input Source Data Tables for Exterior Wall Construction System 0411

The detailed EMERGY input source data tables for the exterior wall construction system 0411 of case study application alternatives A and B are given in Tables 3-4a and 3-4b. Referring to these tables, the system EMERGY input sources of environment (E), fuel energy (F), goods (G), and services (S) are given in columns below EMERGY input source data, and environmental value engineering phases are represented by rows along the left side. Phase EMERGY totals are given in the right column. Total EMERGY for the alternative system is given in the lower right corner of each EMERGY input source data table.

EMERGY input source data for columns (E), (F), (G), and (S) of the data table were obtained from the environmental value engineering EMERGY analysis tables of the designated alternative system for each environmental value engineering phase. These tables are provided in Appendix F. Phase EMERGY totals were obtained by adding phase EMERGY input source data and may also be obtained from the case study application tabular simulation output provided in Appendix H.

Table 3-4a represents the EMERGY input source data for the exterior wall construction system 0411 of case study application alternative A. Comments on the main aspects of Table 3-4a follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No environment input (E) at phases E, F, and H.

TABLE 3-4. DETAILED EMERGY INPUT SOURCE DATA FOR EXTERIOR WALL CONSTRUCTION SYSTEM 0411.

(a) CASE STUDY APPLICATION ALTERNATIVE A.

EVE PHASE	EMERGY INPUT SOURCE DATA (SEJ)				TOTAL PHASE EMERGY
	ENVIRON. (E)	FUEL ENERGY (F)	GOODS (G)	SERVICES (S)	
A-C	1.31E16	1.33E17	3.66E15	5.34E16	2.03E17
D	2.02E13	2.12E14	0	6.52E15	6.75E15
E	0	2.06E15	2.04E14	2.02E15	4.28E15
F	0	2.02E15	3.06E13	1.72E17	1.74E17
G	0	0	0	0	0
H	0	1.60E16	2.38E15	2.78E16	4.62E16
I	0	0	0	0	0
J	9.21E12	5.23E15	2.97E14	1.08E16	1.63E16
TOTAL EMERGY OF ALTERNATIVE A SYSTEM 0411					4.51E17

(b) CASE STUDY APPLICATION ALTERNATIVE B.

EVE PHASE	EMERGY INPUT SOURCE DATA (SEJ)				TOTAL PHASE EMERGY
	ENVIRON. (E)	FUEL ENERGY (F)	GOODS (G)	SERVICES (S)	
A-C	1.98E16	1.47E17	4.42E15	6.11E16	2.32E17
D	2.08E13	2.18E14	0	6.70E15	6.94E15
E	0	0	0	0	0
F	0	2.41E15	5.89E14	5.60E16	5.90E16
G	0	2.41E13	2.41E14	5.12E15	5.39E15
H	0	2.81E16	4.17E15	4.92E16	8.15E16
I	0	0	0	0	0
J	1.10E13	5.84E15	3.32E14	1.20E16	1.82E16
TOTAL EMERGY OF ALTERNATIVE B SYSTEM 0411					4.03E17

3. Goods input (G) at design phase D not included in analysis.
4. Environment input source (E) at design phase D includes land and water use.
5. No use phase G EMERGY input sources.
6. No recycling phase I EMERGY input sources because alternative A assumes no recycling.
7. Environment input source (E) at disposal phase J includes land use based on ratio of land surface area to debris volume for this system of alternative A. Refer to AJ0411 calculations in Appendix F.

Table 3-4b represents the EMERGY input source data for the exterior wall construction system 0411 of case study application alternative B. Comments on the main aspects of Table 3-4b follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No environment input (E) at phases F, G, and H.
3. No EMERGY input sources at component production phase E because concrete tilt-up panels of exterior wall construction system 0411 are produced during construction phase F.
4. Goods input (G) at design phase D not included in analysis.
5. Environment input source (E) at design phase D includes land and water use.
6. EMERGY input sources of (F), (G), and (S) at use

phase G account for periodic replacement of control joints at concrete tilt-up panels of exterior wall construction system 0411.

7. No recycling phase I EMERGY input sources because alternative B assumes no recycling.
8. Environment input source (E) at disposal phase J includes land use based on ratio of land surface area to debris volume. Refer to BJ0411 calculations in Appendix F.

Detailed EMERGY input signatures were constructed to compare detailed input source EMERGY quantities for exterior wall construction system 0411 of case study application alternatives A and B.

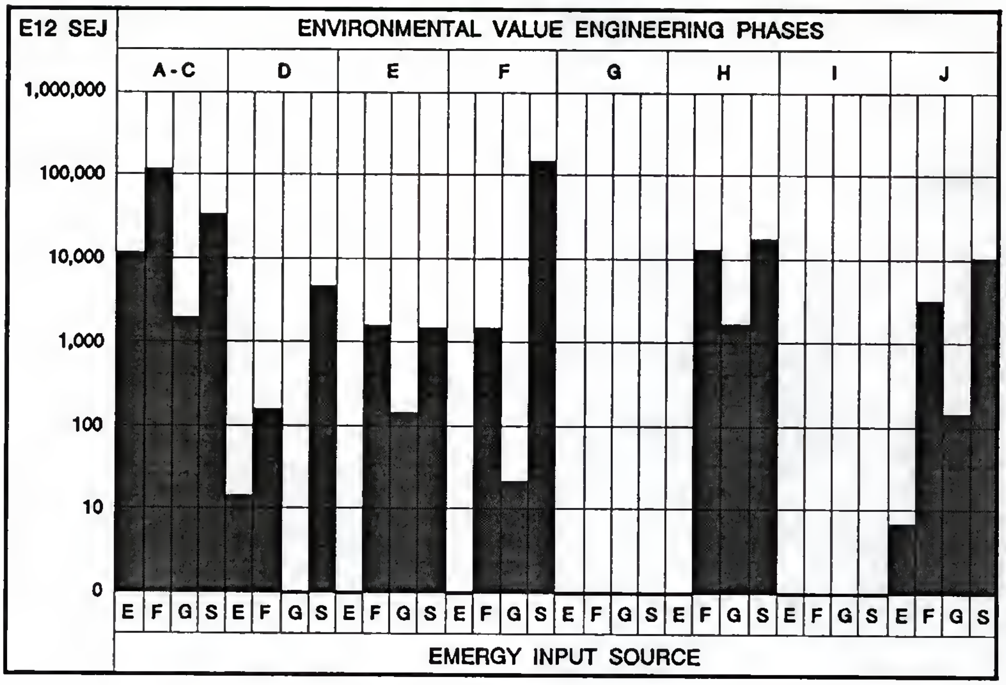
Detailed EMERGY Input Signatures for Exterior Wall Construction System 0411

The detailed EMERGY input signature for the exterior wall construction system 0411 of case study application alternatives A and B are given in Figures 3-3a and 3-3b, respectively. Referring to these figures, the EMERGY input sources of environment (E), fuel energy (F), goods (G), and services (S) for each environmental value engineering phase are given in columns and are labeled along the signature bottom.

Quantities of input source EMERGY, in units of 10^{12} solar emjoules (sej), are represented along the left side of the signature. Each major quantity line represents an order of magnitude of 10 times.

Figure 3-3. Detailed EMERGY input signatures of exterior wall construction system 0411.
(a) Case study application alternative A.
(b) Case study application alternative B.

(a)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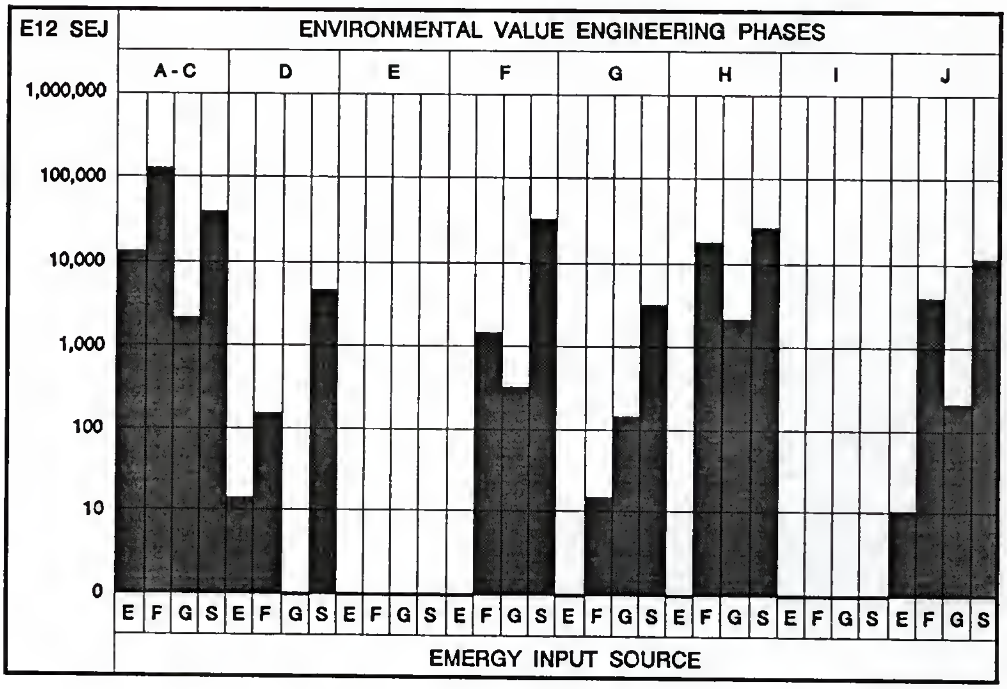
EMERGY INPUT SOURCE

(b)


E12 SEJ
ENVIRONMENTAL VALUE ENGINEERING PHASES
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EMERGY INPUT SOURCE

Environmental value engineering phase input source EMERGY quantities for columns (E), (F), (G), and (S) of Figures 3-3a and 3-3b were obtained from detailed EMERGY input source data Tables 3-4a and 3-4b, respectively.

Figure 3-3a represents the detailed EMERGY input signature for the exterior wall construction system 0411 of case study application alternative A. Comments on the main aspects of Figure 3-3a follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No environment input (E) at phases E, F, and H.
3. Goods input (G) at design phase D not included in analysis.
4. Environment input source (E) at design phase D includes land and water use.
5. No use phase G EMERGY input sources.
6. No recycling phase I EMERGY input sources because alternative A assumes no recycling.
7. Environment input source (E) at disposal phase J includes land use based on ratio of land surface area to debris volume. Refer to AJ0411 calculations in Appendix F.
8. Highest phase EMERGY input occurs at input source of services (S) during phase F.
9. Second and third highest phase input source EMERGY occurs at input sources of fuel energy (F) and services (S) during material transformity phases A-C.

Figure 3-3b represents the detailed EMERGY input signature for the exterior wall construction system 0411 of case study application alternative B. Comments on the main aspects of Figure 3-3b follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No environment input (E) at phases F, G, and H.
3. No EMERGY input sources at component production phase E because concrete tilt-up panels of exterior wall construction system 0411 are produced during construction phase F.
4. Goods input (G) at design phase D not included in analysis.
5. Environment input source (E) at design phase D includes land and water use.
6. EMERGY input sources of (F), (G), and (S) at use phase G account for periodic replacement of control joints between concrete tilt-up panels of exterior wall construction system 0411.
7. No recycling phase I EMERGY input sources because alternative B assumes no recycling.
8. Environment input source (E) at disposal phase J includes land use based on ratio of land surface area to debris volume. Refer to BJ0411 calculations in Appendix F.
9. Two highest phase EMERGY inputs occur at input sources of fuel energy (F) and services (S) during

material transformity phases A-C.

10. Third highest phase input source EMERGY occurs at input source of services (S) during construction phase F.

Comparison of Case Study Application Systems

EMERGY input signatures were utilized to compare the pitched roof construction system 0322 and the exterior wall construction system 0411 of case study application alternatives A and B. The signatures represent total system EMERGY of input sources of environment (E), fuel energy (F), goods (G), and services (S) for each environmental value engineering phase of both case study application alternatives A and B.

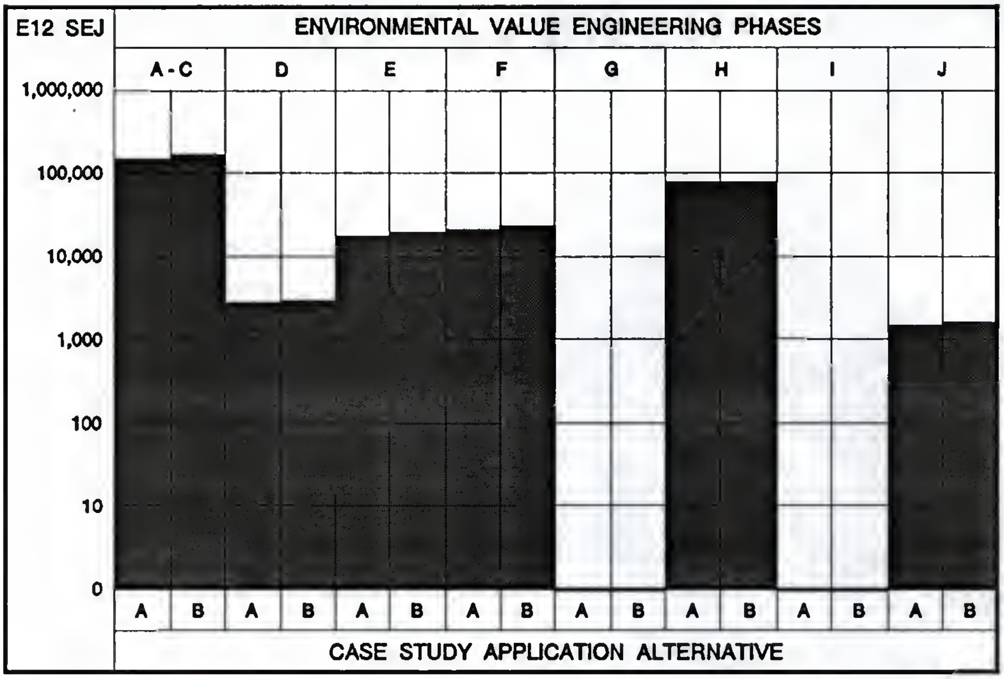
Pitched Roof Construction System 0322

The EMERGY input signature of environmental value engineering phase total EMERGY for the pitched roof construction system 0322 of case study application alternatives A and B is given in Figure 3-4a. Referring to Figure 3-4a, the total EMERGY for each environmental value engineering phase is represented in columns designated for both alternatives A and B.

Quantities of input source EMERGY are represented along the left side of the signature in units of 10^{12} solar emjoules at the same scale as previous EMERGY input signatures in this dissertation. Environmental value engineering phase input source EMERGY quantity totals were obtained from detailed

Figure 3-4. Total system EMERGY input signatures.
(a) Pitched roof construction system 0322.
(b) Exterior wall construction system 0411.

(a)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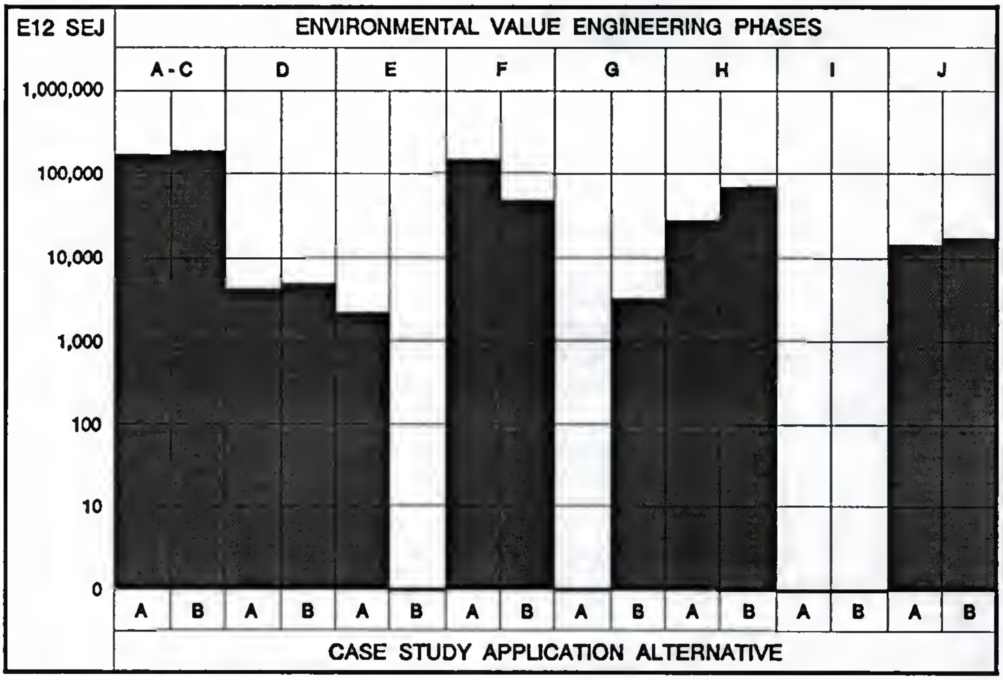
CASE STUDY APPLICATION ALTERNATIVE

(b)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B
CASE STUDY APPLICATION ALTERNATIVE

EMERGY input source data Tables 3-3a and 3-3b.

Comments on the main aspects of Figure 3-4a follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No use phase G input sources.
3. No recycling phase I input sources because alternatives A and B assume no recycling.
4. Phase EMERGY differences between alternatives A and B are not significant because the quantity of steel for pitched roof construction system 0322 is slightly larger for alternative B.
5. Highest phase EMERGY input occurs at material transformity phases A-C of both alternatives A and B.
6. Second highest phase EMERGY occurs during demolition phase H of both alternatives A and B.

Exterior Wall Construction System 0411

The EMERGY input signature of environmental value engineering phase total EMERGY for the exterior wall construction system 0411 of case study application alternatives A and B is given in Figure 3-4b. Referring to Figure 3-4b, the total EMERGY for each environmental value engineering phase is given in columns designated for both alternatives A and B.

Quantities of input source EMERGY are represented along the left side of the signature in units of 10^{12} solar emjoules at the same scale as previous EMERGY input signatures in this dissertation. Environmental value engineering phase input source EMERGY quantity totals were obtained from detailed EMERGY input source data Tables 3-4a and 3-4b.

Comments on the main aspects of Figure 3-4b follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No EMERGY input at component production phase E of alternative B because tilt-up panels of exterior wall construction system 0411 are produced during construction phase F.
3. No use phase G input sources at alternative A.
4. EMERGY input at use phase G of alternative B to account for periodic replacement of control joints between concrete tilt-up panels of exterior wall construction system 0411.
5. No recycling phase I input sources because alternatives A and B assume no recycling.
6. Two highest phase EMERGY inputs occur at material transformity phases A-C of both alternatives A and B.
7. Third highest phase EMERGY input occurs during construction phase F of alternative A.
8. EMERGY input at demolition phase H and disposal phase J are higher for alternative B because of weight and volume differences.

To compare phase EMERGY of case study application alternatives A and B based on the EMERGY of all systems, detailed EMERGY inputs of individual systems were aggregated.

Aggregated EMERGY Input Analysis

The results of the aggregated EMERGY input analysis portion of environmental value engineering for case study application alternatives A and B are represented first by aggregated EMERGY input source data tables and then by translation of this data into aggregated EMERGY input signatures. EMERGY input source data quantities for the aggregated EMERGY input source data tables are obtained from the case study application simulation program tabular output provided in Appendix H.

The following two sections describe aggregated EMERGY input source data table nomenclature, sources of EMERGY input data, and aggregated EMERGY input signatures for case study application alternatives A and B.

Aggregated EMERGY Input Source Data Tables

An aggregated EMERGY input source data table represents the EMERGY of input sources for all systems of an alternative during the 10 phases of environmental value engineering. The aggregated EMERGY input source data tables for case study application alternatives A and B are given in Tables 3-5a and 3-5b, respectively. Referring to Table 3-5a, the EMERGY input sources of environment (E), fuel energy (F), goods (G), and services (S) are given in columns below EMERGY input source data, and environmental value engineering phases are represented by rows along the left side. Phase EMERGY totals are given in the right column. Total EMERGY for the alternative is given in the lower right corner of each EMERGY

TABLE 3-5. AGGREGATED EMERGY INPUT SOURCE DATA.

(a) CASE STUDY APPLICATION ALTERNATIVE A.

EVE PHASE	EMERGY INPUT SOURCE DATA (SEJ)				TOTAL PHASE EMERGY
	ENVIRON. (E)	FUEL ENERGY (F)	GOODS (G)	SERVICES (S)	
A-C	7.48E16	2.10E17	1.02E16	7.50E16	3.70E17
D	3.43E13	3.60E14	0	1.11E16	1.15E16
E	0	4.81E15	3.55E15	2.60E16	3.44E16
F	0	8.51E15	1.04E15	2.00E17	2.10E17
G	0	0	0	0	0
H	0	4.81E16	7.14E15	8.34E16	1.39E17
I	0	0	0	0	0
J	1.04E13	5.88E15	3.33E14	1.21E16	1.84E16
				TOTAL EMERGY OF ALTERNATIVE A	7.83E17

(b) CASE STUDY APPLICATION ALTERNATIVE B.

EVE PHASE	EMERGY INPUT SOURCE DATA (SEJ)				TOTAL PHASE EMERGY
	ENVIRON. (E)	FUEL ENERGY (F)	GOODS (G)	SERVICES (S)	
A-C	8.44E16	2.27E17	1.13E16	8.37E16	4.07E17
D	3.52E13	3.68E14	0	1.13E16	1.17E16
E	0	3.30E15	3.50E15	2.52E16	3.20E16
F	0	9.08E15	1.69E15	8.56E16	9.64E16
G	0	2.41E13	2.41E14	5.12E15	5.39E15
H	0	6.02E16	8.93E15	1.05E17	1.74E17
I	0	0	0	0	0
J	1.23E13	6.51E15	3.70E14	1.34E16	2.03E16
				TOTAL EMERGY OF ALTERNATIVE B	7.46E17

input source data table.

EMERGY input source data for columns (E), (F), (G), and (S) of the data tables were obtained from the case study application tabular simulation output provided in Appendix H. Phase EMERGY totals also were obtained from the tabular simulation output.

Table 3-5a represents the aggregated EMERGY input source data for case study application alternative A. Comments on the main aspects of Table 3-5a follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No environment input (E) at phases E, F, and H.
3. Goods input (G) at design phase D not included in analysis.
4. Environment input source (E) at design phase D includes land and water use.
5. No use phase G EMERGY input sources.
6. No recycling phase I EMERGY input sources because alternative A assumes no recycling.
7. Environment input source (E) at disposal phase J includes land use based on ratio of land surface area to debris volume for systems of alternative A. Refer to calculations in Appendix F.

Table 3-5b represents the aggregated EMERGY input source data for case study application alternative B. Comments on the main aspects of Table 3-5b follow:

1. Refer to Figure 1-3 for environmental value

engineering phase designations.

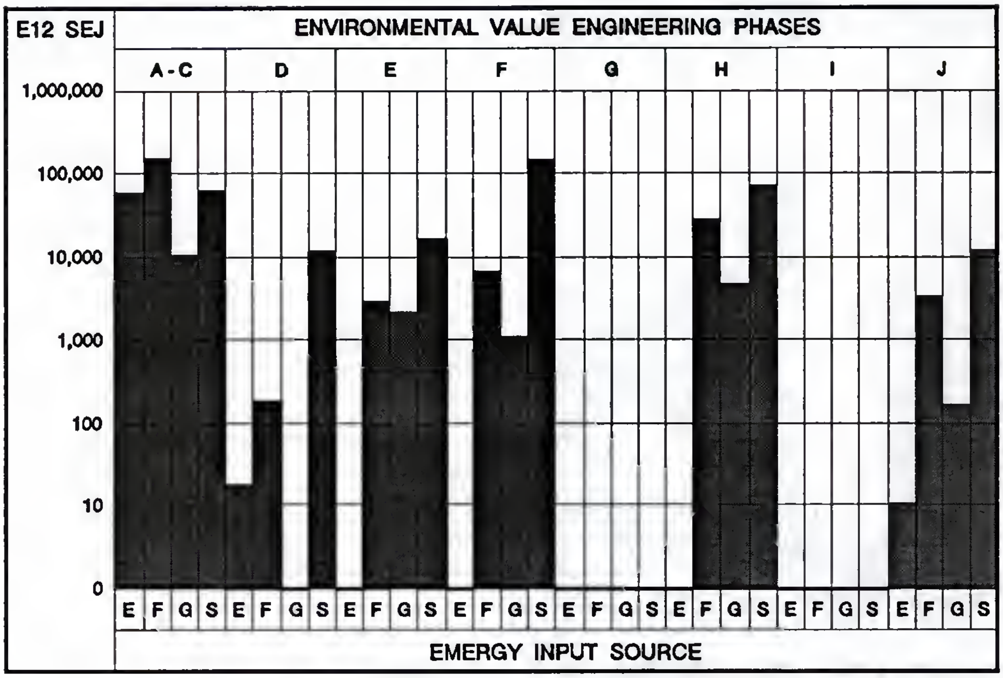
2. No environment input (E) at phases E, F, G, and H.
3. Goods input (G) at design phase D not included in analysis.
4. Environment input source (E) at design phase D includes land and water use.
5. EMERGY input sources of (F), (G), and (S) at use phase G account for periodic replacement of control joints at concrete tilt-up panels of exterior wall construction system 0411.
6. No recycling phase I EMERGY input sources because alternative B assumes no recycling.
7. Environment input source (E) at disposal phase J includes land use based on ratio of land surface area to debris volume for systems of alternative B. Refer to calculations in Appendix F.

Aggregated EMERGY Input Signatures

An aggregated EMERGY input signature represents the total EMERGY of input sources for all systems within a built environment alternative. The aggregated EMERGY input signatures for case study application alternatives A and B are given in Figures 3-5a and 3-5b, respectively. Referring to these figures, the EMERGY input sources of environment (E), fuel energy (F), goods (G), and services (S) for each environmental value engineering phase are given in columns and are labeled along the signature bottom.

Figure 3-5. Aggregated phase EMERGY input signatures.
(a) Case study application alternative A.
(b) Case study application alternative B.

(a)


E12 SEJ
ENVIRONMENTAL VALUE ENGINEERING PHASES
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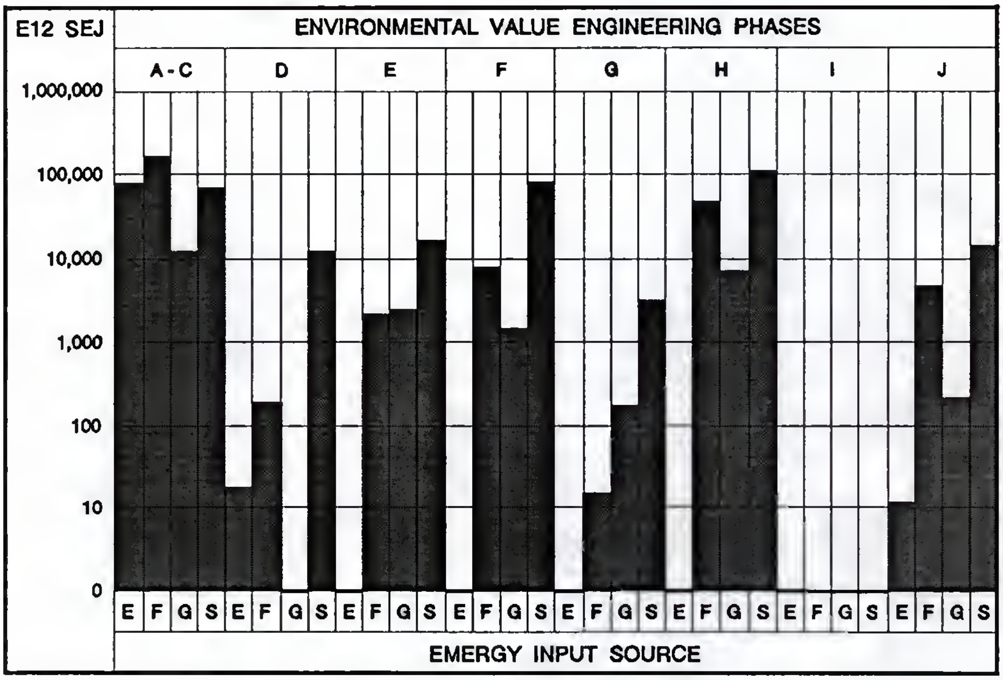
E F G S E F G S E F G S E F G S E F G S E F G S E F G S E F G S
EMERGY INPUT SOURCE

(b)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EMERGY INPUT SOURCE

Quantities of input source EMERGY are represented along the left side of the signature in units of 10^{12} solar emjoules at the same scale as previous EMERGY input signatures in this dissertation.

Environmental value engineering phase input source EMERGY quantities for columns (E), (F), (G), and (S) of Figures 3-5a and 3-5b were obtained from aggregated EMERGY input source data Tables 3-5a and 3-5b, respectively.

Figure 3-5a represents the aggregated EMERGY input signature for case study application alternative A. Comments on the main aspects of Figure 3-5a follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No environment input (E) at phases E, F,and H.
3. Goods input (G) at design phase D not included in analysis.
4. Environment input source (E) at design phase D includes land and water use.
5. Fuel energy input source (F) higher than goods input source (G) at phases A-C, D, E, F, H, and J.
6. No use phase G input sources.
7. No recycling phase I input sources because alternative A assumes no recycling.
8. Environment input source (E) at disposal phase J includes land use based on ratio of land surface area to debris volume for systems of alternative A. Refer to calculations in Appendix F.

9. Highest phase EMERGY input occurs at input source of fuel energy (F) during material transformity phases A-C.
10. Second highest phase EMERGY input occurs at input source of services (S) during construction phase F.

Figure 3-5b represents the aggregated EMERGY input signature for case study application alternative B. Comments on the main aspects of Figure 3-5b follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No environment input (E) at phases E, F, G, and H.
3. Goods input (G) at design phase D not included in analysis.
4. Environment input source (E) at design phase D includes land and water use.
5. Fuel energy input source (F) higher than goods input source (G) at phases A-C, D, F, H, and J.
6. EMERGY input sources of (F), (G), and (S) at use phase G account for periodic replacement of control joints at concrete tilt-up panels of exterior wall construction system 0411.
7. No recycling phase I EMERGY input sources because alternative B assumes no recycling.
8. Environment input source (E) at disposal phase J includes land use based on ratio of land surface area to debris volume for systems of alternative B. Refer to calculations in Appendix F.

9. Highest phase EMERGY input occurs at input source of fuel energy (F) during material transformity phases A-C.
10. Second highest phase EMERGY input occurs at input source of services (S) during demolition phase H.

Comparison of Case Study Application Alternatives

An environmental value engineering analysis includes the comparison of built environment alternatives. This section compares case study application alternatives A and B through use of an aggregated phase EMERGY input signature and a graphical simulation output of cumulative total input source environmental impact EMERGY.

An aggregated EMERGY input signature was utilized to compare the total phase EMERGY of all systems of case study application alternatives A and B. The signature represents total phase EMERGY of input sources of environment (E), fuel energy (F), goods (G), and services (S) for each environmental value engineering phase of both alternatives A and B.

To compare both case study application alternatives A and B over the 10 environmental value engineering phases, a graphical simulation output was produced to represent the cumulative total environmental impact EMERGY of input sources of both alternatives during the 10 phase environmental value engineering analysis period.

The following two sections describe the comparison of case study application alternatives A and B using an aggregated phase EMERGY input signature and a graphical simulation output of cumulative total input source EMERGY.

Aggregated Phase EMERGY Input Signature

An aggregated phase EMERGY input source signature was constructed to represent the total EMERGY of input sources of environment (E), fuel energy (F), goods (G), and services (S) for each environmental value engineering phase of case study application alternatives A and B. Referring to this signature, which is given in Figure 3-6a, the total input source EMERGY quantities for each environmental value engineering phase are indicated in columns designated for both alternatives A and B.

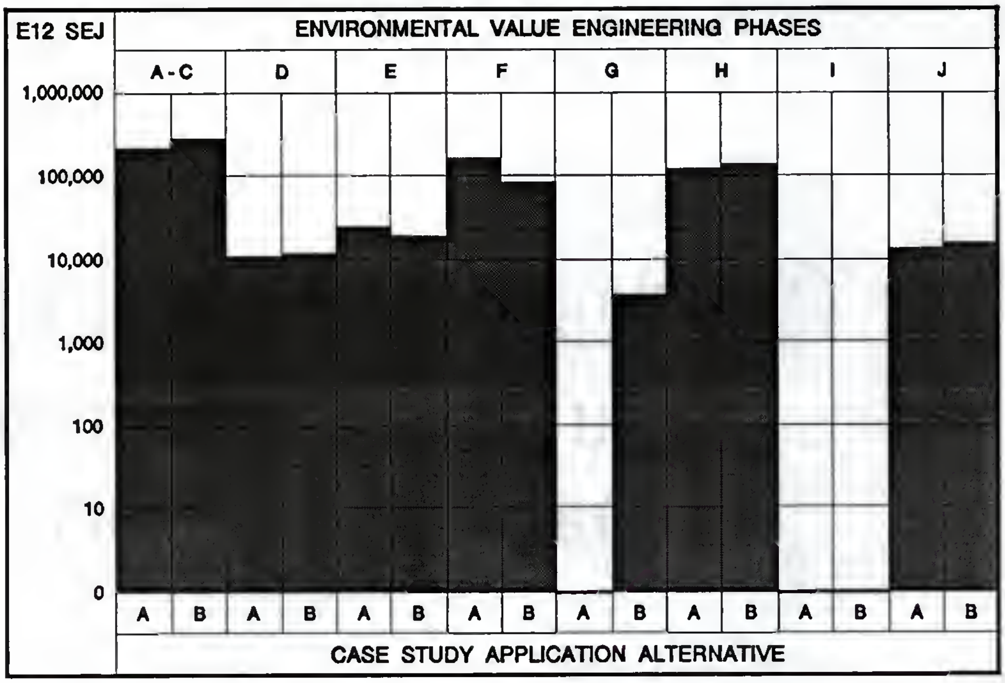
Total phase input source EMERGY quantities were obtained from the total phase EMERGY columns on aggregated EMERGY input source data Tables 3-5a and 3-5b for case study application alternatives A and B, respectively. The quantities represent total phase input source EMERGY of all systems within alternatives A and B. Quantities of input source EMERGY are represented along the left side of the signature in units of 10^{12} solar emjoules at the same scale as previous EMERGY input signatures in this dissertation.

Figure 3-6a represents the aggregated phase EMERGY input signature for case study application alternatives A and B. Comments on the main aspects of Figure 3-6a follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. No use phase G input sources at alternative A.
3. EMERGY input at use phase G of alternative B to account for periodic replacement of control joints

Figure 3-6. Comparison of case study alternatives.
(a) Aggregated phase EMERGY input signature.
(b) Cumulative total input source EMERGY.

(a)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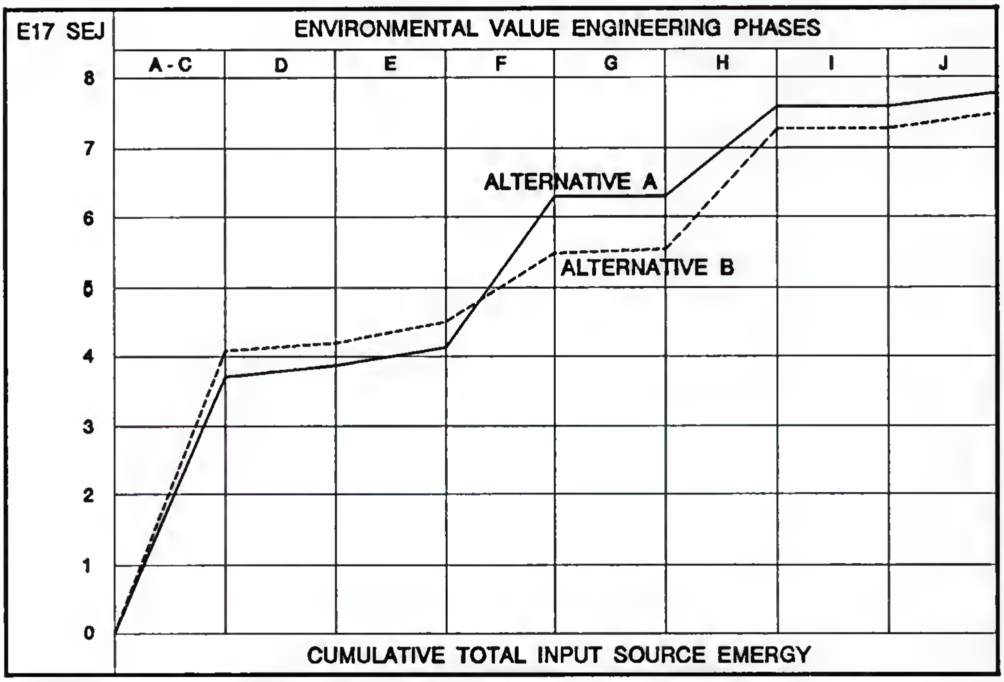
CASE STUDY APPLICATION ALTERNATIVE

(b)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ALTERNATIVE A
ALTERNATIVE B
CUMULATIVE TOTAL INPUT SOURCE EMERGY

between concrete tilt-up panels of exterior wall construction system 0411.

4. No recycling phase I input sources because alternatives A and B assume no recycling.
5. Two highest phase EMERGY inputs occur at material transformity phases A-C for alternatives A and B.
6. Third highest phase EMERGY input occurs during construction phase F at alternatives A.
7. Lowest phase EMERGY input, excluding recycling phase I, occurs at use phase G of alternatives A and B.
8. EMERGY input at design phase D, component production phase E, and disposal phase J are about equal.
9. EMERGY input at alternative A component production phase E and construction phase F is higher than alternative B. Refer to system EMERGY calculations in Appendix F.
10. EMERGY input at demolition phase H and disposal phase J are higher for alternative B because of weight and volume differences.

Utilizing the aggregated phase EMERGY input quantities on a cumulative basis provides the means of comparing case study application alternatives A and B over the life cycle analysis period of the 10 environmental value engineering phases. The following section describes the results of this comparison.

Cumulative Total Input Source EMERGY

Life cycle comparison of the environmental impact EMERGY of built environment alternatives is a key element of an environmental value engineering analysis. To analyze the life cycle environmental impact EMERGY of case study application alternatives A and B, a graphical simulation output was produced to represent the cumulative total environmental impact EMERGY of input sources for both alternatives.

The graphical simulation output of cumulative total environmental impact EMERGY of input sources for case study application alternatives A and B is given in Figure 3-6b. Referring to Figure 3-6b, the cumulative total input source environmental impact EMERGY for both alternatives are indicated through the 10 phase environmental value engineering analysis period, which represents the life cycle for both alternatives.

Quantities of input source environmental impact EMERGY, in units of 10^{17} solar emjoules, are represented along the left side of the graphical simulation output. Environmental value engineering total phase input source EMERGY quantities for case study application alternatives A and B were obtained from the total phase EMERGY column of Tables 3-5a and 3-5b, respectively.

Figure 3-6b represents the graphical simulation output of the cumulative environmental impact EMERGY of case study application alternatives A and B. Comments on the main aspects of Figure 3-6b follow:

1. Refer to Figure 1-3 for environmental value engineering phase designations.
2. Initial total input source EMERGY of alternatives A

and B begin at 0.

3. Slopes of cumulative total input source EMERGY of alternatives do not reflect EMERGY intensity because environmental value engineering phases are not represented by actual phase period lengths.
4. EMERGY intensity of environmental value engineering phases is represented by quantity differences from beginning to end of individual phases.
5. Phase EMERGY intensities of alternatives A and B correspond to total phase EMERGY represented in Figure 3-6a.
6. Two highest EMERGY intensities occur in material transformation phases A-C of alternatives A and B.
7. Highest total input source EMERGY at end of material transformity phases A-C occurs at alternative B.
8. Third highest EMERGY intensity occurs in construction phase F of alternative A.
9. Fourth and fifth highest EMERGY intensities occur in demolition phase H of alternatives A and B.
10. Total input source EMERGY of alternative A surpasses alternative B during construction phase F.
11. No increase in total input source EMERGY at use phase G of alternative A.
12. No increase in total input source EMERGY during recycling phase I because alternatives A and B assume no recycling.
13. Highest total input source EMERGY at end of

environmental value engineering analysis period occurs at alternative A.

The following section discusses more complicated points developed in the environmental value engineering analysis of case study application alternatives A and B.

CHAPTER 4
DISCUSSION

Case Study Application Discussion

Discussion of case study application alternatives A and B is provided in intraphase, interphase, and aggregated phase EMERGY input comparisons, and EVE EMERGY indices.

Intraphase Comparison of EMERGY Input

Detailed EMERGY input signatures (Figures 3-2a, 3-2b, 3-3a, and 3-3b) provided graphical representations of input source EMERGY concentrations that occurred within environmental value engineering phases for the pitched roof construction system 0322 and exterior wall construction system 0411 of case study application alternatives A and B.

Construction phase F of concrete masonry exterior wall construction system 0411 (alternative A) had high EMERGY of services (S) and wide range of variation in input source EMERGY quantities, as shown in Figure 3-3a. The EMERGY input of services (S) in construction phase F accounted for 98.82% of total phase EMERGY, while fuel energy (F) and goods (G) account for 1.16% and 0.02%, respectively.

These findings show large differences between EMERGY input sources. An EMERGY increase in goods (G) could reduce total phase EMERGY by lowering services (S) input source

EMERGY. Substitutions may reduce the cumulative total input source EMERGY of that alternative.

Interphase Comparison of EMERGY Input

Component production phase E and construction phase F of the concrete masonry exterior wall construction system 0411 of case study application alternative A were selected for interphase EMERGY comparison.

Referring to Figure 3-3a and Table 3-4a, the total phase EMERGY of construction phase F was 40.7 times higher than that of component production phase E. This was predominately due to services (S). The EMERGY of services (S) during construction phase F was 85.2 times that of component production phase E.

These findings show a large difference between the total phase EMERGY of these two related phases. The total EMERGY of alternative A possibly could be reduced by lowering the services (S) in phase F through modification of concrete masonry units in production of components in phase E.

Comparison of Aggregated Phase EMERGY

The aggregated EMERGY input signature given in Figure 3-6a provides a graphical representation of total input source EMERGY concentrations that occurred during environmental value engineering phases for all systems of alternatives A and B. The purpose of this section is to compare total aggregated phase EMERGY inputs of both alternatives. Table 4-1 provides an aggregated phase EMERGY comparison based on data from Tables 3-5a and 3-5b.

TABLE 4-1. COMPARISON OF AGGREGATED PHASE EMERGY.

EVE Phase		Alternative Comparison
A-C	Material transformity	A 10.0% less than B
D	Design	A 1.7% less than B
E	Component production	A 7.5% greater than B
F	Construction	A 117.8% greater than B
G	Use	Not applicable
H	Demolition	A 25.2% less than B
I	Natural resource recycling	Not applicable
J	Disposal	A 10.3% less than B

Material transformity phases A-C, which have the highest phase EMERGY, account for 47.3% and 54.6% of the total EMERGY of alternatives A and B, respectively. This strongly indicates that substitution of materials with lower transformities could reduce total EMERGY.

Exclusion of phases from an evaluation may provide false conclusions. For example, when comparing only the sum of component phase E and construction phase F of both alternatives, the phase EMERGY of alternative A is 90.6% greater than alternative B. But, when comparing total EMERGY, alternative A is 5.0% greater than alternative B. To properly evaluate an alternative, aggregated system EMERGY must be accounted for during all 10 phases of the alternative's life cycle.

Environmental Value Engineering EMERGY Indices

Indices of EMERGY per unit of built environment alternative and EMERGY per unit of built environment production output were used to compare case study application alternatives A and B.

The EMERGY per unit of built environment alternative provides a means of comparing EMERGY concentrations. Calculation of this index for exterior wall construction system 0411 of alternatives A and B is provided in Appendix I. For the concrete masonry alternative A, EMERGY was found to be 2.35E13 solar emjoules per square foot, while the concrete tilt-up panel alternative B was 10.6% lower at 2.10E13 solar emjoules per square foot.

The total solar EMERGY per unit energy of built environment production output is the unit's solar transformity (Appendix I, systems 0322 and 0411 of alternatives A and B). The solar transformity per production output unit, an index for systems 0322 and 0411 of the flight-mission alert shelter case study application, was 2.15E13 sej/flight-mission for alternative A and 2.04E13 sej/flight-mission for alternative B, 5.1% lower. The total solar transformity per flight-mission would include all built environment alternative systems, aircraft, and personnel EMERGY.

Implementation of Environmental Value Engineering

Environmental value engineering is an environmental impact EMERGY control technique which has the potential ability to reduce environmental impact significantly. Usage methods could be disseminated through training workshops and the proposed society of environmental value engineering, which are described in the following sections.

Environmental Value Engineering Training Workshop

Environmental value engineering workshops could be conducted to acquaint decision makers with the environmental value engineering analysis system.

The agenda of a training workshop would be similar to that of a value engineering workshop, as described by Zimmerman and Hart (1982). A workshop would be a 40-hour program comprised of lectures, publications, and actual application projects. The workshop would be taught by instructors having knowledge of the analysis system and technical experience in built environment related fields.

Results of a training workshop would be for individuals to have learned standardized principles and techniques of environmental value engineering for application on their own projects. Training workshops would meet minimum criteria established by the society of environmental value engineering, which is described in the following section.

Society of Environmental Value Engineering

The purpose of a society of environmental value engineering is to advance the acceptance and use of environmental value engineering as an analysis system to analyze the environmental impact of built environment alternatives. Information could be disseminated through publications, meetings, programs, seminars, and conferences. Environmental value engineering may have a wider audience than value engineering because of the increase in public concern about the environment.

The society of environmental value engineering could serve as an environmental impact EMERGY database center for environmental value engineering users. The society of environmental value engineering also would serve as a network for users to advance environmental value engineering as a marketable analysis system. Users, through their membership fees, would receive state-of-the-art information on environmental value engineering. Membership fees also would be used to fund research on environmental value engineering applications and advancement.

Future Research and Applications

Further application of environmental value engineering analysis system could be for automobiles, aircraft, appliances, equipment, machinery, et cetera. Like built environment alternatives these products go through the 10 environmental value engineering life cycle phases (Figure 1-3).

Areas of refinement requiring further research include

1. additional environmental impacts incorporated in source input transformities,
2. development of additional input source transformities,
3. development of condensed, user-friendly simulation programs, as described in the Object-oriented, Knowledge-based Expert Systems Application section described later,
4. integration of environmental value engineering EMERGY analysis tables into the simulation program,
5. evaluation and inclusion of the EMERGY input of bare land due to the geological cycle that maintains continents above the sea, and
6. additional input source data.

Methods of environmental value engineering refinement include the following:

1. implementation and use,
2. research,

3. development of increased levels of detail, while maintaining the whole,
4. transformities developed in similar fashion to case study application for use in future environmental value engineering analyses, and
5. continual refinement similar to refinement process of the EMERGY analysis system.

Environmental value engineering refinement may result in more accurate environmental decision-making analyses. This would increase the acceptance and use of environmental value engineering, which ultimately would reduce the environmental impact of the built environment.

Environmental Impact EMERGY Database

EMERGY data are scarce because the number of analysts is small. Currently, EMERGY analyses are primarily conducted by individuals who have learned EMERGY analysis techniques from the group at Gainesville, Florida. Data do exist on embodied energy (Hannon et al., 1976), which is different from EMERGY because environment, goods, and services inputs and energy quality were not considered. EMERGY data currently are available in the form of a transformity list, which is used during the EMERGY analysis process. There is need for an environmental impact EMERGY database related to the built environment because such a database does not exist.

Through the use of environmental value engineering, a built environment impact EMERGY database could be established on environmental value engineering phases and built environment alternative types. After a period of transition, the database could be maintained by the architecture and engineering professions.

The built environment impact EMERGY database would be continuously updated with the latest EMERGY information to provide more accurate environmental value engineering analyses. This built environment impact EMERGY information may affect future building code requirements as society progresses toward sustainable development.

EMERGY Relationship to Building Code Requirements

Building code occupancy groups and types of construction requirements resulting in high EMERGY should be considered for modification.

Existing occupancy groups and types of construction, as presented in the 1991 Uniform Building Code (International Conference of Building Officials, 1991), would be used as categories for which EMERGY data would be collected, and actual applications of the environmental value engineering analysis system would be conducted to evaluate built environment alternatives related to building code requirements. An example evaluation would be the EMERGY of a sprinklered alternative versus one that is not sprinklered.

Evaluation results would be used to calculate environmental value engineering EMERGY indices for comparing built environment alternatives based on the correlation of EMERGY and building code requirements.

Research findings on the EMERGY relationship to building code requirements may direct future building codes toward sustainable development.

Object-oriented, Knowledge-based Expert Systems Application

An object-oriented, knowledge-based expert system has a frame-based systems structure instead of the rule-based systems structure of traditional expert systems. According to Mockler (1989), object-oriented systems and structures appear to have potential usefulness in developing larger, more advanced management decision-making systems. Environmental value engineering is such a decision-making system. The frame or object-based structure of object-oriented, knowledge-based expert systems could be applied to environmental value engineering.

The systems structures of object-oriented, knowledge-based expert systems and environmental value engineering are based on hierarchical collections of objects. In environment value engineering the objects of a built environment alternative are a hierarchy of EMERGY inputs to materials, components, and systems. As a built environment alternative goes through the 10 phases, the properties of some objects remain the same, while other objects vary. Each object has its own variables. Some are inherited and some are unique.

The EMERGY of a built environment alternative is affected by the relationships or interactions that built environment alternative objects have with each other. With object-oriented, knowledge-based expert systems, these relationships and interactions can be handled internally by an object-oriented, knowledge-based expert systems computer program. Data such as materials, systems, EMERGY input sources, quantities, and phase times could be requested by the computer program.

Object-oriented, knowledge-based expert systems applications could be developed for the decision-making processes that occur during environmental value engineering life cycle phases. For example, during demolition phase H, decisions must be made to recycle built environment alternative materials, components, and systems or to dispose of them.

Geographic Information Systems Application

Geographic Information Systems are computerized mapping processes which involve the establishment of digital geographic databases that contain land use information. Geographic Information Systems technology has evolved from several disciplines, including cartography, remote sensing, and geography (Norton & Slonecker, 1990). Geographic Information Systems provide the ability to store, retrieve, and analyze geographic information. Environmental value engineering output provides built environment impact EMERGY information related to geographic locations. Therefore, research potential exists in the area of Geographic Information Systems and environmental value engineering integration.

Geographic Information Systems could be used to monitor EMERGY concentrations related to natural resource and energy flow distributions from sources to built environment production, consumption, and storage processes. Environmental value engineering can be utilized to provide the EMERGY information about built environment alternatives. From this EMERGY information, Geographic Information Systems could provide maps of EMERGY and transformity for use in urban planning and the setting of built environment policies related to environmental impact EMERGY.

Closing Remarks

Environmental value engineering provides a method to analyze EMERGY of environment, fuel energy, goods, and services inputs used in built environment alternatives. Optimum use of these EMERGY inputs contributes more wealth and provides more sustainable development. According to the World Commission on Environment and Development (1987, p. 43), "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Sustainable development is dependent on the availability of EMERGY input from environment, fuel energy, goods, and services components. Lotka (1925), states that an essential component presented in limited supply acts as a check or brake, as a limiting factor. Increases in available components will have little or no effect on production of development (built environment) due to the limited component. According to

Odum (1988), if by the year 2100 the main fuels and mineral resources have been depleted, economies will have contracted and populations will have declined. The United States energy budget will average about 26% of the 1980 level (Odum, 1988). Anticipation of this lower energy state will smooth the transition.

Odum (1991, p. 93) states, "that greatest public wealth can be achieved by policies that bring in the most EMERGY and allocate it to uses that reinforce production, including environmental production processes on which the human production systems depend." Selection of built environment alternatives which contribute the most EMERGY to the economy while drawing the least from it are possible through use of environmental value engineering.

APPENDIX A

COMPARISON OF EMERGY AND EMBODIED ENERGY

Aluminum.

Embodied energy:
113,049 BTU/lb [Hannon et al., 1978]
39,800 sej/CEJ [Appendix D and see note 1]
(113,049 BTU/lb)(1055 CEJ/BTU) = 1.19E8 CEJ/lb
(1.19E8 CEJ/lb)(39,800 sej/CEJ) = 4.74E12 sej/lb

EMERGY:
1.60E10 sej/g [Appendix D]
(1.60E10 sej/g)(453.6 g/lb) = 7.26E12 sej/lb

Comparison of EMERGY to embodied energy:
(7.26E12 sej/lb)/(4.74E12 sej/lb)
= 1.50 times more EMERGY per unit

Steel (carbon).

Embodied energy:
17,808 BTU/lb [Hannon et al., 1978]
(17,808 BTU/lb)(1055 CEJ/BTU) = 1.88E7 CEJ/lb
(1.88E7 CEJ/lb)(39,800 sej/CEJ) = 7.48E11 sej/lb

EMERGY:
1.80E9 sej/g [Appendix D]
(1.80E9 sej/g)(453.6 g/lb) = 8.17E11 sej/lb

Comparison of EMERGY to embodied energy:
(8.17E11 sej/lb)/(7.48E11 sej/lb)
= 1.09 times more EMERGY per unit

Wood.

Embodied energy:
5,229 BTU/BF [Hannon et al., 1978]
(5,229 BTU/BF)(1055 CEJ/BTU) = 5.52E6 CEJ/BF
(5.52E6 CEJ/BF)(39,800 sej/CEJ) = 2.20E11 sej/BF

EMERGY:
3.49E4 sej/J [Appendix D]
(3.49E4 sej/J)(2.4E3 cm^3/BF)(0.7 g/cm^3)(3.8 kcal/g)
(4186 J/kcal) = 9.33E11 sej/BF

Comparison of EMERGY to embodied energy:
(9.33E11 sej/BF)/(2.20E11 sej/BF)
= 4.24 times more EMERGY per unit

Concrete.

Embodied energy:
2,584,938 BTU/CY [Hannon et al., 1978]
3,900 lb/CY [Siddens, 1989]
(2,584,938 BTU/CY)/(3,900 lb/CY) = 663 BTU/lb
(663 BTU/lb)((1055 CEJ/BTU) = 7.00E5 CEJ/lb
(7.00E5 CEJ/lb)(39,800 sej/CEJ) = 2.79E10 sej/lb

EMERGY:
2.40E8 sej/g [Appendix D]
(2.40E8 sej/g)(453.6 g/lb) = 1.09E11 sej/lb

Comparison of EMERGY to embodied energy:
(1.09E11 sej/lb)/(2.79E10 sej/lb)
= 3.91 times more EMERGY per unit

Notes:
1. Coal equivalent joules abbreviated CEJ.
2. Refer to Glossary for definition of embodied energy used in this dissertation.

APPENDIX B

ENVIRONMENTAL IMPACT EMERGY INPUT SOURCES

✓

PHASE A. Natural Resource Formation

- E. Environment (renewable)
  - E1. Atmosphere
  - E2. Ecological production
  - E3. Energy
    - (1) Sun
    - (2) Earth
  - E4. Land
    - (1) Area
    - (2) Resources
  - E5. Water
    - (1) Area
    - (2) Resources
- F. Fuel Energy (nonrenewable): none
- G. Goods: none
- S. Services (labor): none

PHASE B. Natural Resource Exploration and Extraction

- E. Environment (renewable)
  - E1. Atmosphere
  - E2. Ecological production
  - E3. Energy
    - (1) Sun
    - (2) Earth
  - E4. Land
    - (1) Area
    - (2) Resources
  - E5. Water
    - (1) Area
    - (2) Resources
- F. Fuel Energy (nonrenewable)
  - F1. Equipment
  - F2. Facilities
- G. Goods
  - G1. Equipment
  - G2. Facilities
  - G3. Materials
  - G4. Tools
- S. Services
  - S1. Labor

PHASE C. Material Production

- E. Environment (renewable)
  - E1. Atmosphere
  - E2. Ecological production
  - E3. Energy
    - (1) Sun
    - (2) Earth

    - E4. Land
        - (1) Area
        - (2) Resources
    - E5. Water
        - (1) Area
        - (2) Resources
- F. Fuel Energy (nonrenewable)
    - F1. Equipment
    - F2. Facilities
- G. Goods
    - G1. Equipment
    - G2. Facilities
    - G3. Materials
    - G4. Tools
- S. Services
    - S1. Labor

PHASE D. Design (Architectural and Engineering)

- E. Environment (renewable)
    - E1. Atmosphere
    - E2. Ecological production
    - E3. Energy
        - (1) Sun
        - (2) Earth
    - E4. Land
        - (1) Area
        - (2) Resources
    - E5. Water
        - (1) Area
        - (2) Resources
- F. Fuel Energy (nonrenewable)
    - F1. Equipment
    - F2. Facilities
- G. Goods
    - G1. Equipment
    - G2. Facilities
    - G3. Materials
    - G4. Tools
- S. Services
    - S1. Labor

PHASE E. Component Production

- E. Environment (renewable)
    - E1. Atmosphere
    - E2. Ecological production
    - E3. Energy
        - (1) Sun
        - (2) Earth
    - E4. Land
        - (1) Area
        - (2) Resources
    - E5. Water
        - (1) Area
        - (2) Resources

- F. Fuel Energy (nonrenewable)
  - F1. Equipment
  - F2. Facilities
- G. Goods
  - G1. Equipment
  - G2. Facilities
  - G3. Materials
  - G4. Tools
- S. Services
  - S1. Labor

PHASE F. Construction

- E. Environment (renewable)
  - E1. Atmosphere
  - E2. Ecological production
  - E3. Energy
    - (1) Sun
    - (2) Earth
  - E4. Land
    - (1) Area
    - (2) Resources
  - E5. Water
    - (1) Area
    - (2) Resources
- F. Fuel Energy (nonrenewable)
  - F1. Equipment
  - F2. Facilities
- G. Goods
  - G1. Equipment
  - G2. Facilities
  - G3. Materials
  - G4. Tools
- S. Services
  - S1. Labor

PHASE G. Use

- E. Environment (renewable)
  - E1. Atmosphere
  - E2. Ecological production
  - E3. Energy
    - (1) Sun
    - (2) Earth
  - E4. Land
    - (1) Area
    - (2) Resources
  - E5. Water
    - (1) Area
    - (2) Resources
- F. Fuel Energy (nonrenewable)
  - F1. Equipment
  - F2. Facilities
- G. Goods
  - G1. Equipment
  - G2. Facilities

    - G3. Materials
    - G4. Tools
  - S. Services
    - S1. Labor

PHASE H. Demolition

  - E. Environment (renewable)
    - E1. Atmosphere
    - E2. Ecological production
    - E3. Energy
      - (1) Sun
      - (2) Earth
    - E4. Land
      - (1) Area
      - (2) Resources
    - E5. Water
      - (1) Area
      - (2) Resources
  - F. Fuel Energy (nonrenewable)
    - F1. Equipment
    - F2. Facilities
  - G. Goods
    - G1. Equipment
    - G2. Facilities
    - G3. Materials
    - G4. Tools
  - S. Services
    - S1. Labor

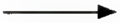
PHASE I. Natural Resource Recycling

  - E. Environment (renewable)
    - E1. Atmosphere
    - E2. Ecological production
    - E3. Energy
      - (1) Sun
      - (2) Earth
    - E4. Land
      - (1) Area
      - (2) Resources
    - E5. Water
      - (1) Area
      - (2) Resources
  - F. Fuel Energy (nonrenewable)
    - F1. Equipment
    - F2. Facilities
  - G. Goods
    - G1. Equipment
    - G2. Facilities
    - G3. Materials
    - G4. Tools
  - S. Services
    - S1. Labor

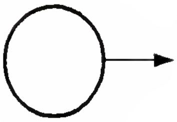
PHASE J. Disposal
- E. Environment (renewable)
    - E1. Atmosphere
    - E2. Ecological production
    - E3. Energy
        - (1) Sun
        - (2) Earth
    - E4. Land
        - (1) Area
        - (2) Resources
    - E5. Water
        - (1) Area
        - (2) Resources
- F. Fuel Energy (nonrenewable)
    - F1. Equipment
    - F2. Facilities
- G. Goods
    - G1. Equipment
    - G2. Facilities
    - G3. Materials
    - G4. Tools
- S. Services
    - S1. Labor

APPENDIX C

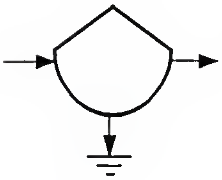
ENERGY SYSTEMS DIAGRAM SYMBOLS AND LANGUAGE



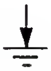
Energy circuit. A pathway whose flow is proportional to the quantity in the storage or source upstream.



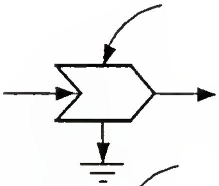
Source. Outside source of energy delivering forces according to a program controlled from outside; a forcing function



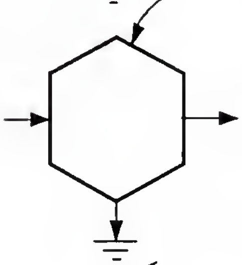
Tank. A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.



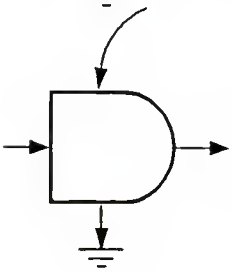
Heat sink. Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.



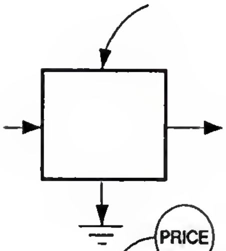
Interaction. Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate.



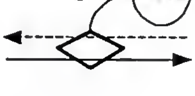
Consumer. Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.



Producer. Unit that collects and transforms low-quality energy under control interactions of high-quality flows.



Box. Miscellaneous symbol to use for whatever subsystem, unit or function is labeled.



Transaction. A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed line). Price is shown as an external source.

APPENDIX D

TRANSFORMITIES

Transformities (EMERGY conversions) for energies, resources, and commodities related to the built environment.

MATERIAL	TRANSFORMITIES (Refer to notes 1 and 2.)
Aluminum inguts (g)	1.60E10
Asphalt (J)	3.47E5
Cement (g)	3.30E10
Coal (J)	3.98E4
Concrete (g)	2.40E8
Copper (g)	6.80E10
Electricity (J)	1.59E5
Glass (g)	8.40E8
Iron (g)	1.80E9
Machinery (g)	6.70E9
Natural gas (J)	4.80E4
Oil (J)	5.30E4
Paper (J)	2.15E5
Petroleum product (J)	6.60E4
Plastic (g)	3.80E8
Rubber (g)	4.30E9
Service, labor (Dollar)	2.00E12 (Refer to note 3.)
Steel (g)	1.80E9
Topsoil (J)	6.30E4
Water, consumer (J)	6.66E5
Water, waste (J)	4.10E4
Wood (J)	3.49E4
Zinc Alloys (g)	6.80E10

Notes:

1. Transformity units are solar emjoules/Joule, solar emjoules/gram or solar emjoules/US $.
2. Source: Gainesville, University of Florida, Environmental Engineering Sciences course EES 5306, taught by Dr. Howard T. Odum. Used with his permission.
3. Units in 1990 U. S. dollars.

APPENDIX E

UNIFORMAT CODE OF ACCOUNTS

- 01 Foundations
    - 011 Standard Foundations
        - 0111 Wall Foundations
        - 0112 Column Foundations and Pile Caps
    - 012 Special Foundation Conditions
        - 0121 Pile Foundations
        - 0122 Caissons
        - 0123 Underpinning
        - 0124 Dewatering
        - 0125 Raft Foundations
        - 0126 Other Special Foundation Conditions

- 02 Substructure
    - 021 Slab on Grade
        - 0211 Standard Slab on Grade
        - 0212 Structural Slab on Grade
        - 0213 Inclined Slab on Grade
        - 0214 Trenches, Pits, and Bases
        - 0215 Foundation Drainage
    - 022 Basement Excavation
        - 0221 Excavation for Basements
        - 0222 Structural Backfill and Compaction
        - 0223 Shoring
    - 023 Basement Walls
        - 0231 Basement Wall Construction
        - 0232 Moisture Protection
        - 0233 Basement Wall Insulation

- 03 Superstructure
    - 031 Floor Construction
        - 0311 Suspended Basement Floor Construction
        - 0312 Upper Floor Construction
        - 0313 Balcony Construction
        - 0314 Ramps
        - 0315 Special Floor Construction
    - 032 Roof Construction
        - 0321 Flat Roof Construction
        - 0322 Pitched Roof Construction
        - 0323 Canopies
        - 0324 Special Roof Systems
    - 033 Stair Construction
        - 0331 Stair Structure

- 04 Exterior Closure
    - 041 Exterior Walls
        - 0411 Exterior Wall Construction

        - 0412 Exterior Louvers and Screens

    - 0413 Sun Control Devices (Exterior)
    - 0414 Balcony Walls and Handrails
    - 0415 Exterior Soffits
  - 042 Exterior Doors and Windows
    - 0421 Windows
    - 0422 Curtain Walls
    - 0423 Exterior Doors
    - 0424 Storefronts

- 05 Roofing
    - 0501 Roof Covering
    - 0502 Traffic Toppings
    - 0503 Roof insulation and Fill
    - 0504 Flashings and Trim
    - 0505 Roof Openings

- 06 Interior Construction
  - 061 Partitions
    - 0611 Fixed Partitions
    - 0612 Demountable Partitions
    - 0613 Retractable Partitions
    - 0614 Compartments and Cubicles
    - 0615 Interior Balustrades and Screens
    - 0616 Interior Doors and Frames
    - 0617 Interior Storefronts
  - 062 Interior Finishes
    - 0621 Wall Finishes
    - 0622 Flooring
    - 0623 Ceiling Finishes
  - 063 Specialties
    - 0631 General Specialties
    - 0632 Built-in Fittings

- 07 Conveying Systems
    - 0701 Elevators
    - 0702 Moving Stairs and Walks
    - 0703 Dumbwaiters
    - 0704 Pneumatic Tube Systems
    - 0705 Other Conveying Systems
    - 0706 General Construction Items

- 08 Mechanical
  - 081 Plumbing
    - 0811 Domestic Water Supply System
    - 0812 Sanitary Waste and Vent System
    - 0813 Rainwater Drainage System
    - 0814 Plumbing Fixtures
  - 082 HVAC
    - 0821 Energy Supply
    - 0822 Heat Generation System
    - 0823 Cooling Generation Systems
    - 0824 Distribution Systems
    - 0825 Terminal and Package Units
    - 0826 Controls and Instrumentation

    - 0827 Systems Testing and Balancing
  - 083 Fire Protection
    - 0831 Water Supply (Fire Protection)
    - 0832 Sprinklers
    - 0833 Standpipe Systems
    - 0834 Fire Extinguishers
  - 084 Special Mechanical Systems
    - 0841 Special Plumbing Systems
    - 0842 Special Fire Protection Systems
    - 0843 Miscellaneous Special Systems and devices

- 09 Electrical
  - 091 Service and Distribution
    - 0911 High Tension Service and Distribution
    - 0912 Low Tension Service and Distribution
  - 092 Lighting and Power
    - 0921 Branch Wiring
    - 0922 Lighting Equipment
  - 093 Special Electrical Systems
    - 0931 Communications and Alarm Systems
    - 0932 Grounding Systems
    - 0933 Emergency Light and Power
    - 0934 Electric Heating
    - 0935 Floor Raceway Systems
    - 0936 Other Special Systems and Devices
    - 0937 General Construction Items

- 10 General Conditions and Profit
    - 1001 Mobilization and Initial Expenses
    - 1002 Site Overhead
    - 1003 Demobilization
    - 1004 Main Office Expenses and Profit

- 11 Equipment
  - 111 Fixed and Movable Equipment
    - 1111 Built-in Maintenance Equipment
    - 1112 Checkroom Equipment
    - 1113 Food Service Equipment
    - 1114 Vending Equipment
    - 1115 Waste Handling Equipment
    - 1116 Loading Dock Equipment
    - 1117 Parking Equipment
    - 1118 Detention Equipment
    - 1119 Postal Equipment
  - 112 Furnishings
    - 1121 Artwork
    - 1122 Window Treatment
    - 1123 Seating
  - 113 Special Construction
    - 1131 Vaults
    - 1132 Interior Swimming Pools
    - 1133 Modular Prefabricated Assemblies
    - 1134 Special Purpose Rooms
    - 1135 Other Special Construction

- 12 Site Work
  - 121 Site Preparation
    - 1211 Clearing
    - 1212 Demolition
    - 1213 Site Earthwork
  - 122 Site Improvements
    - 1221 Parking Lots
    - 1222 Roads, Walks, and Terraces
    - 1223 Site Development
    - 1224 Landscaping
  - 123 Site Utilities
    - 1231 Water Supply and Distribution
    - 1232 Drainage and Sewerage Systems
    - 1233 Heating and Cooling Systems
    - 1234 Gas Distribution Systems
    - 1235 Electrical Distribution and Lighting Systems
    - 1236 Snow Melting Systems
    - 1237 Service Tunnels
  - 124 Off-Site Work
    - 1241 Railroad Work
    - 1242 Marine Work
    - 1243 Tunneling
    - 1244 Other Off-Site Work

Reference: (General Services Administration, 1981).

APPENDIX F

CASE STUDY APPLICATION EVE EMERGY ANALYSIS TABLES

TABLE F-1. AC0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT	[RE: CALCULATION BACK-UP]		6.17E16
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY	[RE: CALCULATION BACK-UP]		7.68E16
F1	Equipment	NA		
F2	Facilities	NA		
G	GOODS	[RE: CALCULATION BACK-UP]		6.56E15
G1	Equipment	NA		
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES	[RE: CALCULATION BACK-UP]		2.16E16
S1	Labor	NA		

AC0322 EMERGY INPUT CALCULATION BACK-UP

Steel transformity = 1.80E9 sej/g
Petroleum product transformity = 6.60E4 sej/J
[Appendix D]
Steel quantity = (200,066 lb)(453.6 g/lb
= 9.08E7 g [Material take-off]
Petroleum product quantity = (9.08E7 g)(2%) = 1.82E6 g
(1.82E6 g)/((9 lb/Gal)(55 Gal/BBL)(453.6 g/lb))
(6.28E9 J/BBL) = 5.09E10 J

E. Environment.

Steel
Environmental input transformity portion = 37.3 %
[Odum, in press]
(1.80E9 sej/g)(0.373) = 6.71E8 sej/g
(9.08E7 g)(6.71E8 sej/g) = 6.09E16 sej
Petroleum product
Environmental input transformity portion = 25 %
[Estimate]
(6.60E4 sej/J)(0.25) = 1.65E4 sej/J
(5.09E10 J)(1.65E4 sej/J) = 8.40E14 sej

Total environmental input = 6.17E16 sej

F. Fuel energy.

Steel
Fuel energy input transformity portion = 46.5 %
[Odum, in press]
(1.80E9 sej/g)(0.465) = 8.37E8 sej/g
(9.08E7 g)(8.37E8 sej/g) = 7.60E16 sej
Petroleum product
Fuel energy input transformity portion = 25 %
[Estimate]
(6.60E4 sej/J)(0.25) = 1.65E4 sej/J
(5.09E10 J)(1.65E4 sej/J) = 8.40E14 sej

Total fuel energy input = 7.68E16 sej

G. Goods.

Steel
Goods input transformity portion = 3.5 %
[Odum, in press]
(1.80E9 sej/g)(0.035) = 6.30E7 sej/g
(9.08E7 g)(6.30E7 sej/g) = 5.72E15 sej
Petroleum product
Goods input transformity portion = 25 %
[Estimate]
(6.60E4 sej/J)(0.25) = 1.65E4 sej/J
(5.09E10 J)(1.65E4 sej/J) = 8.40E14 sej

Total goods input = 6.56E15 sej

S. Services.

Steel

Services input transformity portion = 12.7 %

[Odum, in press]

(1.80E9 sej/g)(0.127) = 2.29E8 sej/g

(9.08E7 g)(2.29E8 sej/g) = 2.08E16 sej

Petroleum product

Services input transformity portion = 25 %

[Estimate]

(6.60E4 sej/J)(0.25) = 1.65E4 sej/J

(5.09E10 J)(1.65E4 sej/J) = 8.40E14 sej

Total services input = 2.16E16 sej

TABLE F-2. AC0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT	[RE: CALCULATION BACK-UP]		1.31E16
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY	[RE: CALCULATION BACK-UP]		1.33E17
F1	Equipment	NA		
F2	Facilities	NA		
G	GOODS	[RE: CALCULATION BACK-UP]		3.66E15
G1	Equipment	NA		
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES	[RE: CALCULATION BACK-UP]		5.34E16
S1	Labor	NA		

AC0411 EMERGY INPUT CALCULATION BACK-UP

Steel transformity = 1.80E9 sej/g
Concrete transformity = 2.40E8 sej/g
[Appendix D]
Steel quantity = 1.70E7 g [Material take-off]
Concrete quantity = 7.19E8 g [Material take-off]

E. Environment.
Steel
Environmental input transformity portion = 37.3 %
[Odum, in press]
(1.80E9 sej/g)(0.373) = 6.71E8 sej/g
(1.70E7 g)(6.71E8 sej/g) = 1.14E16 sej
Concrete
Environmental input transformity portion = 1 %
[Brown % McClanahan, 1992]
(2.40E8 sej/g)(0.01) = 2.40E6 sej/g
(7.19E8 g)(2.40E6 sej/g) = 1.73E15 sej

Total environmental input = 1.31E16 sej

F. Fuel energy.
Steel
Fuel energy input transformity portion = 46.5 %
[Odum, in press]
(1.80E9 sej/g)(0.465) = 8.37E8 sej/g
(1.70E7 g)(8.37E8 sej/g) = 1.42E16 sej
Concrete
Fuel energy input transformity portion = 68.8 %
[Brown & McClanahan, 1992]
(2.40E8 sej/g)(0.688) = 1.65E8 sej/g
(7.19E8 g)(1.65E8 sej/g) = 1.19E17 sej

Total fuel energy input = 1.33E17 sej

G. Goods.
Steel
Goods input transformity portion = 3.5 %
[Odum, in press]
(1.80E9 sej/g)(0.035) = 6.30E7 sej/g
(1.70E7 g)(6.30E7 sej/g) = 1.07E15 sej
Concrete
Goods input transformity portion = 1.5 %
[Brown & McClanahan, 1992]
(2.40E8 sej/g)(0.015) = 3.60E6 sej/g
(7.19E8 g)(3.60E6 sej/g) = 2.59E15 sej

Total goods input = 3.66E15 sej

S. Services.

Steel

Services input transformity portion = 12.7 %
[Odum, in press]

(1.80E9 sej/g)(0.127) = 2.29E8 sej/g

(1.70E7 g)(2.29E8 sej/g) = 3.89E15 sej

Concrete

Services input transformity portion = 28.7 %
[Brown & McClanahan, 1992]

(2.40E8 sej/g)(0.287) = 6.89E7 sej/g

(7.19E8 g)(6.89E7 sej/g) = 4.95E16 sej

Total services input = 5.34E16 sej

TABLE F-3. AD0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			1.41E13
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	1.42E10 J	1	1.42E10
E5	Water	2.12E7 J	6.66E5	1.41E13
F	FUEL ENERGY			1.48E14
F1	Equipment	NA		
F2	Facilities	9.29E8 J	1.59E5	1.48E14
G	GOODS			0
G1	Equipment	NA		
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES			4.56E15
S1	Labor	2.28E3 $	2.00E12	4.56E15

AD0322 EMERGY INPUT CALCULATION BACK-UP

E. Environment.

E4. Land.

Design facility ground floor area = 5200 SF
[Rogers, Lovelock,& Fritz, Inc.,
Winter Park, Florida]

Project portion of facility use = 20% [Estimate]

Project design duration = 14 months

System 0322 portion of total project =
\$100,903/\$3,702,083 = 0.2726
[Project Time & Cost, Inc., 1988]

Land surface sunlight calculations:
(Facility ground area)(Average of insolation)

Avg. net absorbed solar radiation = 110 kcal/cm^2/yr
[Odum, 1990]

(5200 SF)(929.03 cm^2/SF)(110 kcal/cm^2/yr)(0.20)
(14 mo/12 mo/yr)(0.02726)(4186 J/kcal) = 1.42E10 J

E5. Water.

Project design budget = 5568 hours

Total 1991 design phase water consumption
= 791,000 gal
[Rogers, Lovelock,& Fritz, Inc.,
Winter Park, Florida]

Total 1991 design phase labor = 101,121 hours
[Rogers, Lovelock,& Fritz, Inc.,
Winter Park, Florida]

Water consumption/labor hr = 791,000 gal/101,121 hrs
= 7.8 gal/hr

Gibbs free energy in water = 4.94 J/g [Odum, 1990]

(5568 hr)(0.02726)(7.8 gal/hr)(8 lb/gal)(453.6 g/lb)
(4.94 J/g) = 2.12E7 J

F. Fuel energy.

F2. Facility.

Project design budget = 5568 hours

Total 1991 design phase electric consumption
= 172,200 kWh
[Rogers, Lovelock,& Fritz, Inc.,
Winter Park, Florida]

Total 1991 design phase labor = 101,121 hours
[Rogers, Lovelock,& Fritz, Inc.,
Winter Park, Florida]

Electric consumption/labor hr
= 172,200 kWh/101,121 hrs
= 1.7 kWh/hr

(5568 hr)(0.02726)(1.7 kWh/hr)(3.60E6 J/kWh)
= 9.29E8 J

G. Goods.

Not available. Use input = 0.

S. Services.

S1. Labor.

Project design labor budget = \$83,700

(\$83,700)(0.02726) = 2.28E3 \$

TABLE F-4. AD0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			2.02E13
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	2.02E10 J	1	2.02E10
E5	Water	3.03E7 J	6.66E5	2.02E13
F	FUEL ENERGY			2.12E14
F1	Equipment	NA		
F2	Facilities	1.33E9 J	1.59E5	2.12E14
G	GOODS			0
G1	Equipment	NA		
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES			6.52E15
S1	Labor	3.26E3 $	2.00E12	6.52E15

AD0411 EMERGY INPUT CALCULATION BACK-UP

E. Environment.

E4. Land.

Design facility ground floor area = 5200 SF
[Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]
Project portion of facility use = 20% [Estimate]
Project design duration = 14 months
System 0411 portion of total project =
$144,193/$3,702,083 = 0.03895
[Project Time & Cost, Inc., 1988]
Land surface sunlight calculations:
(Facility ground area)(Average of insolation)
Avg. net absorbed solar radiation = 110 kcal/cm^2/yr
[Odum, 1990]
(5200 SF)(929.03 cm^2/SF)(110 kcal/cm^2/yr)(0.20)
(14 mo/12 mo/yr)(0.03895)(4186 J/kcal) = 2.02E10 J

E5. Water.

Project design budget = 5568 hours
Total 1991 design phase water consumption
= 791,000 gal
[Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]
Total 1991 design phase labor = 101,121 hours
[Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]
Water consumption/labor hr = 791,000 gal/101,121 hrs
= 7.8 gal/hr
Gibbs free energy in water = 4.94 J/g [Odum, 1990]
(5568 hr)(0.03895)(7.8 gal/hr)(8 lb/gal)(453.6 g/lb)
(4.94 J/g) = 3.03E7 J

F. Fuel energy.

F2. Facility.

Project design budget = 5568 hours
Total 1991 design phase electric consumption
= 172,200 kWh [Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]
Total 1991 design phase labor = 101,121 hours
[Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]
Electric consumption/labor hr
= 172,200 kWh/101,121 hrs = 1.7 kWh/hr
(5568 hr)(0.03895)(1.7 kWh/hr)(3.60E6 J/kWh)
= 1.33E9 J

G. Goods.

Not available. Use input = 0.

S. Services.

S1. Labor.

Project design labor budget = $83,700
($83,700)(0.03895) = 3.26E3 $

TABLE F-5. AE0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY			2.75E15
F1	Equipment	4.17E10 J	6.60E 4	2.75E15
F2	Facilities	NA		
G	GOODS			3.35E15
G1	Equipment	NA		
G2	Facilities	NA		
G3	Materials	5.07E10 J	6.60E4	3.35E15
G4	Tools	NA		
S	SERVICES			2.40E16
S1	Labor	1.20E4 $	2.00E12	2.40E16

AE0322 EMERGY INPUT CALCULATION BACK-UP

E. Environment.
    Not available. Use input = 0.

F. Fuel energy.
    F1. Equipment.
        Flat-bed transports (20 ton maximum)
            Total system 0322 weight = 200,066 lb
                                        [Material take-off]
            (200,066 lb)/(2000 lb/ton)/(20 ton/transport)
                = 5 transports
            System 0322 to Homestead Air Force Base,
              FL from Stark, FL & return = 365 miles
            Transport fuel consumption = 5 mpg [Estimate]
        (5)(365 mi)/(5mpg)/(55 gal/BBL)(6.28E9 J/BBL)
            = 4.17E10 J

G. Goods.
    G3. Materials.
        Petroleum Product, structural steel paint
            Total system 0322 wt. =
                (200,066 lb)(453.6 g/lb) = 9.08E7 g
            Structural steel paint wt. = 2% of system wt.
        (9.08E7 g)(0.02)/(2.25E5 g/BBL)(6.28E9 J/BBL)
            = 5.07E10 J

S. Services.
    S1. Labor.
        System 0322 output = 200 ton/week [Estimate]
            Labor hours/200 tons = 4005 hours [Estimate]
            Average 1989 labor salary = $6/hr [Estimate]
        (200 ton/wk)(2000 lb/ton)/(4005 hours/week)
            = 100 lb/hour
        (200,066 lb)/(100 lb/hour)($6.00/hour)
            = 1.20E4 $

TABLE F-6. AE0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY			2.06E15
F1	Equipment	1.30E10 J	6.60E4	8.58E14
F2	Facilities	7.52E9 J	1.59E5	1.20E15
G	GOODS			2.04E14
G1	Equipment	3.04E4 g	6.70E9	2.04E14
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES			2.02E15
S1	Labor	1.01E3 $	2.00E12	2.02E15

AE0411 EMERGY INPUT CALCULATION BACK-UP

E. Environment.

Not available. Use input = 0.

F. Fuel energy.

F1. Equipment.

Concrete masonry unit (CMU) production.

[Information from June 11, 1992 interview with Charmco Byrd of Rinker Materials, Inc. concrete masonry unit plant in Ocala, Florida]

4"x8"x16" = 0.5 CMU

8"x8"x16" = 1.0 CMU

12"x8"x16" = 1.5 CMU

8"x8"x16" CMU output/month = 256,000

(1) Clark 75B front-end loader

(1) Caterpillar V150 lift truck

(2) Caterpillar V90E lift trucks

(1) Front-end loader

Use: (2 hrs/shift)(2 shifts/day)(21.67 days/mo) = 87 hrs/month

Fuel consumption = 6 gal/hr [Estimate]

12"x8"x16" CMU for AE0411 = 17,052 [Material take-off]

4"x8"x16" CMU for AE0411 = 4,536 [Material take-off]

Total CMU for AE0411 = (17,052)(1.5)+(4,536)(0.5) = 27,846 CMU

(27,846)/(256,000)(87 hrs)(6 gal/hr)/(55 gal/BBL)(6.28E9 J/BBL) = 6.48E9 J

(3) Lift trucks

Use: Same as front end loader. [Estimate]

Fuel consumption = 2 gal/hr [Estimate]

(3)(27,846)/(256,000)(87 hr)(2 gal/hr)/(55 gal/BBL)(6.28E9 J/BBL) = 6.48E9 J

Total F1 equipment units = 1.30E10 J

F2. Facility.

Concrete masonry unit (CMU) production

[Information from June 11, 1992 interview with Charmco Byrd of Rinker Materials, Inc. concrete masonry unit plant in Ocala, Florida]

Electric consumption/month = 19,120 kwh

8"x8"x16" CMU output/month = 256,000

Total CMU for AE0411 = (17,052)(1.5)+(4,536)(0.5) = 27,846 CMU [AE411, F1]

(19,120)/(256,000) = 0.075 kwh/CMU

(27,846 CMU)(0.075 kwh/CMU) = 2088 kwh

(2088 kwh)(3.30E6 J/kwh) = 7.52E9 J

G. Goods.

G1. Equipment.

(1) Front-end loader

Useful life = 10,000 hours [Estimate]

Weight = 36,900 lb

[Similar to Caterpillar 966C]

Use: 87 hrs/month [AE0411, F1]

(87 hr/mo)(27,846 CMU)/(256,000 CMU/mo)/
(10,000 hr life)(36,900 lb)(453.6 g/lb)
= 1.58E4 g

(3) Lift trucks

Useful life = 15,000 hours [Estimate]

Weight = 17,000 lb

Use: 87 hrs/month [AE0411, F1]

(3)(87 hr/mo)(27,846 CMU)/(256,000 CMU/mo)/
(15,000 hr life)(17,000 lb)(453.6 g/lb)
= 1.46E4 g

Total G1 equipment units = 3.40E4 g

S. Services.

S1. Labor.

Concrete masonry unit (CMU) production.

[Information from June 11, 1992 interview with Charmco Byrd of Rinker Materials, Inc. concrete masonry unit plant in Ocala, Florida]

Labor hours/month = 1160

Average 1990 labor salary = $8/hr

(27,846 CMU)/(256,000 CMU/mo)
(1160 hrs/mo)($8/hr) = 1.01E3 $

TABLE F-7. AF0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY			6.49E15
F1	Equipment	9.84E10 J	6.60E4	6.49E15
F2	Facilities	NA		
G	GOODS			1.01E15
G1	Equipment	1.51E5 g	6.70E9	1.01E15
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES			2.84E16
S1	Labor	1.42E4 $	2.00E12	2.84E16

AF0322 EMERGY INPUT CALCULATION BACK-UP

E. Environment.
- Not available. Use input = 0.

F. Fuel energy.
- F1. Equipment.
  - F1A. At open-web joists.
    - E-7 crew [R. S. Means Company, 1992]
    - (1) Crane, 90 ton [Use Manitowoc M-85W]
      - Fuel consumption = 5 gal/hr [Estimate]
      - Use = 41.9 hrs [AF0322, G1A]
      - (41.9 hrs use)(5 gal/hr) = 209.5 gal
      - (209.5 gal)(55 gal/BBL)(6.28E9 J/BBL) = 2.39E10 J
    - (2) Welding machines, gas
      - Fuel consumption = 5 gal/hr [Estimate]
      - (2)(41.9 hrs use)(5 gal/hr) = 419 gal
      - (419 gal)(55 gal/BBL)(6.28E9 J/BBL) = 4.78E10 J
  - F1B. At metal decking.
    - E-4 crew [R. S. Means Company, 1992]
    - (1) Welding machine, gas
      - Fuel consumption = 5 gal/hr [Estimate]
      - (2)(46.8 hrs use)(5 gal/hr) = 234 gal
      - (234 gal)(55 gal/BBL)(6.28E9 J/BBL) = 2.67E10 J
  - Total F1 equipment units = 9.84E10 J

G. Goods.
- G1. Equipment.
  - G1A. At open-web joists.
    - E-7 crew [R. S. Means Company, 1992]
    - 60.8 ton of 96' joists [Material take-off]
    - 7.3 ton of 30' joists [Material take-off]
    - Crew output at 96' joists = 1.625 ton/hr [R. S. Means Company, 1992]
    - Crew output at 30' joists = 1.5 ton/hr [R. S. Means Company, 1992]
    - (1) Crane, 90 ton
      - Weight = 156,000 lb [Estimate]
      - Useful life = 20,000 hrs [Estimate]
      - (60.8 ton)/(1.625 ton/hr) = 37 hr
      - (7.3 ton)/(1.5 ton/hr) = 4.9 hr
      - Total use = 41.9 hrs
      - (41.9 hrs)/(20,000 hrs)(156,000 lb)(453.6 g/lb) = 1.48E5 g
    - (2) Welding machines, gas
      - Weight = 1,500 lb [Estimate]
      - Useful life = 20,000 hrs [Estimate]
      - (41.9 hrs)/(20,000 hrs)(1,500 lb)(453.6 g/lb) = 1.43E3 g
  - G1B. At metal decking.
    - E-4 crew [R. S. Means Company, 1992]

(1) Welding machine, gas
Weight = 1,500 lb [Estimate]
Useful life = 20,000 hrs [Estimate]
Metal decking area = 26,300 SF
[Material take-off]
Crew output = 562.5 SF/hr
[R. S. Means Company, 1992]
(26,300 SF)/(562.5 SF/hr) = 46.8 hrs
(46.8 hrs)/(20,000 hrs)(1,500 lb)
(453.6 g/lb) = 1.59E3 g

Total G1 equipment units = 1.51E5 g

S. Services.

S1. Labor.

S1A. At open-web joists.
E-4 crew [R. S. Means Company, 1990]
Crew labor at 96' joists = $145/ton
[R. S. Means Company, 1990]
Crew labor at 30' joists = $155/ton
[R. S. Means Company, 1990]
Labor at 96' joists = (60.8 ton)($145/ton)
= $8816
Labor at 30' joists = (7.3 ton)($155/ton)
= $1132

S1B. At metal decking.
Metal decking: 1.5" deep, 22 Ga., >50 Sq.
Crew labor at metal decking = $0.16/SF
[R. S. Means Company, 1990]
(26,300 SF)($0.16/SF) = $4208

Total S1 labor units = 1.42E4 $

TABLE F-8. AF0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY			2.02E15
F1	Equipment	3.06E10 J	6.60E4	
F2	Facilities	NA		
G	GOODS			3.06E13
G1	Equipment	4.56E3 g	6.70E9	3.06E13
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES			1.72E17
S1	Labor	8.59E4 $	2.00E12	1.72E17

AF0411 EMERGY INPUT CALCULATION BACK-UP

E. Environment.
    Not available. Use input = 0.

F. Fuel energy.
    F1. Equipment.
        F1A. At 4"CMU.
            D-8 crew [R. S. Means Company, 1992]
                Crew output = 43 SF/hr
            4" CMU area = 4032 SF [Material take-off]
                (4032 SF)/(43 SF/hr) = 94 hrs
            (1) Mortar &grout mixer, gas
                Fuel consumption = 2 gal/hr [Estimate]
                Use = 25% of output hours [Estimate]
                (94 hrs)(0.25)(2 gal/hr)/(55 gal/BBL)
                (6.28E9 J/BBL) = 5.37E9 J
        F1B. At 12"CMU.
            D-9 crew [R. S. Means Company, 1992]
                Crew output = 34.4 SF/hr
            12" CMU area = 15,157 SF [Material take-off]
                (15,157 SF)/(34.4 SF/hr) = 441 hrs
            (1) Mortar & grout mixer, gas
                Fuel consumption = 2 gal/hr [Estimate]
                Use = 25% of output hours [Estimate]
                (441 hrs)(0.25)(2 gal/hr)/(55 gal/BBL)
                (6.28E9 J/BBL) = 2.52E10 J
    Total F1 equipment units = 3.06E10 J

G. Goods.
    G1. Equipment.
        G1A. At 4" CMU.
            (1) Mortar & grout mixer, gas.
                Weight = 750 lb [Estimate]
                Useful life = 10,000 hrs [Estimate]
                Use = 25% of output hours [Estimate]
                (94hrs)(0.25)/(10,000 hrs)(750 lb)
                (453.6 g/lb) = 8.00E2 g
        G1B. At 12" CMU.
            (1) Mortar & grout mixer, gas.
                Weight = 750 lb [Estimate]
                Useful life = 10,000 hrs [Estimate]
                Use = 25% of output hours [Estimate]
                (441hrs)(0.25)/(10,000 hrs)(750 lb)
                (453.6 g/lb) = 3.76E3 g
    Total G1 equipment units = 4.56E3 g

S. Services.
    S1. Labor.
        S1A. At 4" CMU.
            D-8 crew [R. S. Means Company, 1992]

                4" CMU crew labor = $2.34/SF
                [R. S. Means Company, 1990]

4" CMU area = 4032 SF [Material take-off]
(4032 SF)($2.34/SF) = $9,435
Grout.
Grout crew labor = $0.67/SF
[R. S. Means Company, 1990]
(4032 SF)($0.67) = $2701
S1B. At 12" CMU.
D-9 crew [R. S. Means Company, 1992]
12" CMU Crew labor = $3.44/SF
[R. S. Means Company, 1990]
12" CMU area = 15,157 SF [Material take-off]
(15,157 SF)($3.44/SF) = $52,140
Grout.
Grout crew labor = $0.78/SF
[R. S. Means Company, 1990]
(15,157 SF)($0.78) = $11,823
Horizontal joint reinforcement (Truss-type).
Horiz. joint rein. = 11,916 LF
[Material take-off]
Horiz. joint rein. labor = $0.09/LF
[R. S. Means Company, 1990]
(11,916 LF)($0.09/LF) = $1072
Horizontal reinforcement (#6).
Horizontal reinforcement = 9953 lb
[Material take-off]
Horizontal reinforcement labor = $0.22/lb
[R. S. Means Company, 1990]
(9953 lb)($0.22/lb) = $2190
Vertical reinforcement (#6).
Vertical reinforcement = 24,129 lb
[Material take-off]
Vertical reinforcement labor = $0.27/lb
[R. S. Means Company, 1990]
(24,129 lb)($0.27/lb) = $6515
Total S1 labor units = 8.59E4 $

TABLE F-9. AG0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere			
E2	Ecol. Prod.			
E3	Energy			
E4	Land			
E5	Water			
F	FUEL ENERGY			0
F1	Equipment			
F2	Facilities			
G	GOODS			0
G1	Equipment			
G2	Facilities			
G3	Materials			
G4	Tools			
S	SERVICES			0
S1	Labor			

AG0322 EMERGY INPUT CALCULATION BACK-UP

E. Environment.

Environment input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0322 of alternative A did not require environment input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Replacement.
5. Repair.

Environment input = 0.

F. Fuel energy.

Fuel energy input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0322 of alternative A did not require fuel energy input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Replacement.
5. Repair.

Fuel energy input = 0.

G. Goods.

Goods input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0322 of alternative A did not require goods input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Replacement.

5. Repair.

Goods input = 0.

S. Services.

Services input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0322 of alternative A did not require services input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Replacement.
5. Repair.

Services input = 0.

TABLE F-10. AG0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere			
E2	Ecol. Prod.			
E3	Energy			
E4	Land			
E5	Water			
F	FUEL ENERGY			0
F1	Equipment			
F2	Facilities			
G	GOODS			0
G1	Equipment			
G2	Facilities			
G3	Materials			
G4	Tools			
S	SERVICES			0
S1	Labor			

AG0411 EMERGY INPUT CALCULATION BACK-UP

E. Environment.

Environment input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0411 of alternative A did not require environment input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Replacement.
5. Repair.

Environment input = 0.

F. Fuel energy.

Fuel energy input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0411 of alternative A did not require fuel energy input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Replacement.
5. Repair.

Fuel energy input = 0.

G. Goods.

Goods input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0411 of alternative A did not require goods input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Replacement.

5. Repair.

Goods input = 0.

S. Services.

Services input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0411 of alternative A did not require services input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Replacement.
5. Repair.

Services input = 0.

TABLE F-11. AH0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY			3.21E16
F1	Equipment	4.86E11 J	6.60E4	3.21E16
F2	Facilities	NA		
G	GOODS			4.76E15
G1	Equipment	7.11E5 g	6.70E9	4.76E15
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES			5.56E16
S1	Labor	2.78E4 $	2.00E12	5.56E16

AH0322 EMERGY INPUT CALCULATION BACK-UP

E. Environment.
Not available. Use input = 0.

F. Fuel energy.
F1. Equipment.
B-8 crew [R. S. Means Company, 1992]
(2) Dump trucks, 16 ton
(1) Front-end loader, 2.5 CY
(1) Hydraulic crane, 25 ton
Demolition output = 2500 CF/hr
[R. S. Means Company, 1992]
Building volume = 925,000 CF
[Architectural drawings]
System 0211 portion of demolition = 25%
System 0322 portion of demolition = 50%
System 0411 portion of demolition = 25%
[Estimate]
Duration = (925,000 CF)/(2500 CF/hr)(0.5) = 185 hrs
(2) Dump trucks, 16 ton
Fuel consumption = 7.5 gal/hr [Estimate]
(2)(185 hrs)(7.5 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 3.17E11 J
(1) Front-end loader, 2.5 CY [Caterpillar 936]
Fuel consumption = 4 gal/hr
[Caterpiller, 1986]
(185 hrs)(4 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 8.45E10 J
(1) Hydraulic crane, 25 ton
Fuel consumption = 4 gal/hr [Estimate]
(185 hrs)(4 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 8.45E10 J
Total F1 equipment units = 4.86E11 J

G. Goods.
G1. Equipment.
B-8 crew [R. S. Means Company, 1992]
Duration = 185 hrs [AH0322, F1]
(2) Dump trucks, 16 ton
Weight = 19,120 lb
[Waste Management, Alachua County
Public Works Department,
Gainesville, Florida]
Useful life = 15,000 hrs [Estimate]
(2)(185 hrs)/(15,000 hrs)(19,120 lb)
(453.6 g/lb) = 2.14E5 g
(1) Front-end loader, 2.5 CY [Caterpillar 936]
Weight = 26,600 lb [Caterpiller, 1986]
Useful life = 10,000 hrs [Caterpiller, 1986]
(185 hrs)/(10,000 hrs)(26,600 lb)
(453.6 g/lb) = 2.23E5 g
(1) Hydraulic crane, 25 ton
Weight = 48,987 lb [Link-Belt HSP-8025S]

Useful life = 15,000 hrs [Estimate]
(185 hrs)/(15,000 hrs)(48,987 lb)
(453.6 g/lb) = 2.74E5 g
Total G1 equipment units = 7.11E5 g

S. Services.
S1. Labor.
B-8 crew [R. S. Means Company, 1992]
Crew labor = $0.06/CF [R. S. Means Company, 1990]
Building volume = 925,000 CF
[Architectural drawings]
System 0322 portion of demolition = 50%
(925,000 CF)($0.06/CF)(0.50) = $27,750
Total S1 labor units = 2.78E4 $

TABLE F-12. AH0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY			1.60E16
F1	Equipment	2.42E11 J	6.60E4	1.60E16
F2	Facilities	NA		
G	GOODS			2.38E15
G1	Equipment	3.55E5 g	6.70E9	2.38E15
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES			2.78E16
S1	Labor	1.39E4 $	2.00E12	2.78E16

AH0411 EMERGY INPUT CALCULATION BACK-UP

E. Environment.

Not available. Use input = 0.

F. Fuel energy.

F1. Equipment.

B-8 crew for CMU walls [R. S. Means Company, 1992]

(2) Dump trucks, 16 ton
(1) Front-end loader, 2.5 CY
(1) Hydraulic crane, 25 ton

Demolition output = 2500 CF/hr [R. S. Means Company, 1992]

Building volume = 925,000 CF [Architectural drawings]

System 0211 portion of demolition = 25%
System 0322 portion of demolition = 50%
System 0411 portion of demolition = 25% [Estimate]

Duration = (925,000 CF)/(2500 CF/hr)(0.25)
= 92.5 hrs

(2) Dump trucks, 16 ton
Fuel consumption = 7.5 gal/hr [Estimate]
(2)(92.5 hrs)(7.5 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 1.58E11 J

(1) Front-end loader, 2.5 CY [Caterpillar 936]
Fuel consumption = 4 gal/hr [Caterpiller, 1986]
(92.5 hrs)(4 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 4.22E10 J

(1) Hydraulic crane, 25 ton
Fuel consumption = 4 gal/hr [Estimate]
(92.5 hrs)(4 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 4.22E10 J

Total F1 equipment units = 2.42E11 J

G. Goods.

G1. Equipment.

B-8 crew [R. S. Means Company, 1992]
Duration = 92.5 hrs [AH0322, F1]

(2) Dump trucks, 16 ton
Weight = 19,120 lb [Waste Management, Alachua County Public Works Department, Gainesville, Florida]
Useful life = 15,000 hrs [Estimate]
(2)(92.5 hrs)/(15,000 hrs)(19,120 lb)
(453.6 g/lb) = 1.07E5 g

(1) Front-end loader, 2.5 CY [Caterpillar 936]
Weight = 26,600 lb [Caterpiller, 1986]
Useful life = 10,000 hrs [Caterpiller, 1986]
(92.5 hrs)/(10,000 hrs)(26,600 lb)
(453.6 g/lb) = 1.11E5 g

(1) Hydraulic crane, 25 ton

Weight = 48,987 lb [Link-Belt HSP-8025S]
Useful life = 15,000 hrs [Estimate]
(92.5 hrs)/(15,000 hrs)(48,987 lb)
(453.6 g/lb) = 1.37E5 g
Total G1 equipment units = 3.55E5 g

S. Services.
S1. Labor.
B-8 crew [R. S. Means Company, 1992]
Crew labor = \$0.06/CF [R. S. Means Company, 1990]
Building volume = 925,000 CF
[Architectural drawings]
System 0322 portion of demolition = 50%
(925,000 CF)(\$0.06/CF)(0.25) = \$13,875
Total S1 labor units = 1.39E4 \$

TABLE F-13. AI0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere			
E2	Ecol. Prod.			
E3	Energy			
E4	Land			
E5	Water			
F	FUEL ENERGY			0
F1	Equipment			
F2	Facilities			
G	GOODS			0
G1	Equipment			
G2	Facilities			
G3	Materials			
G4	Tools			
S	SERVICES			0
S1	Labor			

AI0322 EMERGY INPUT CALCULATION BACK-UP

All EMERGY inputs equal zero because alternative A assumes no recycling of demolition debris.

TABLE F-14. AI0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere			
E2	Ecol. Prod.			
E3	Energy			
E4	Land			
E5	Water			
F	FUEL ENERGY			0
F1	Equipment			
F2	Facilities			
G	GOODS			0
G1	Equipment			
G2	Facilities			
G3	Materials			
G4	Tools			
S	SERVICES			0
S1	Labor			

AI0411 EMERGY INPUT CALCULATION BACK-UP

All EMERGY inputs equal zero because alternative A assumes no recycling of demolition debris.

TABLE F-15. AJ0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			2.76E10/yr
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	2.76E10J/yr	1	2.76E10/yr
E5	Water	NA		
F	FUEL ENERGY			6.46E14
F1	Equipment	9.79E9 J	6.60E4	6.46E14
F2	Facilities	NA		
G	GOODS			3.67E13
G1	Equipment	5.34E3 g	6.70E9	3.58E13
G2	Facilities	NA		
G3	Materials	4.91E2 g	1.80E9	8.84E11
G4	Tools	NA		
S	SERVICES			9.76E14
S1	Labor	4.88E2 $	2.00E12	9.76E14
S2	Labor	3.97 $/yr	2.00E12	7.94E12/yr

AJ0322 EMERGY INPUT CALCULATION BACK-UP

Disposal phase calculations are based on data obtained during February 11, 1992 and June 8, 1992 interviews with John H. Carter, Assistant Public Works Director, Waste Management, Alachua County Public Works Department, Gainesville, Florida.

E. Environment.
E4. Land.
Alachua County construction and demolition landfill land surface area = 40 acres
Alachua County construction and demolition landfill depth = 70 feet
Alachua County construction and demolition landfill capacity
= (40 A)(43,560 SF/A)(70 ft)/(27 CF/CY)
= 4.52E6 CY
Ratio of land surface area/CY of landfill capactiy
= (40 A)(43,560 SF/A)/(4.52E6 CY)
= 0.386 SF/CY
Compacted demolition debris weight = 1,200 lb/CY
System A_0322 weight = 200,066 lb [AC0322]
Calculation of A_0322 landfill surface area portion
= (200,066 lb)/(1,200 lb/CY)(0.386 SF/CY)
= 64.4 SF
Avg. net absorbed solar radiation = 110 kcal/cm^2/yr [Odum, 1990]
Annual landfill surface sunlight calculations = (Landfill surface area)(Average of insolation)
= (64.4 SF)(929.03 cm^2/SF)(110 kcal/cm^2/yr) (4186 J/kcal) = 2.76E10 J/yr

F. Fuel energy.
F1. Equipment for demolition debris placement and compaction.
Landfill equipment:
(1) Bulldozer, Caterpillar D-8
Use = 54 hours/month
(1) Front-end loader, 2.5 CY
Use = 67 hours/ month
Alachua County construction and demolition landfill debris = 2.60E6 lb/mo
Compacted demolition debris weight = 1,200 lb/CY
System A_0322 weight = 200,066 lb [AC0322]
(1) Bulldozer, Caterpillar D-8
Fuel consumption = 15 gal/hr [Caterpillar, 1986]
((200,066 lb)/(2.60E6 lb/mo)(54 hrs/mo) (15 gal/hr))/(55 gal/BBL)(6.28E9 J/BBL)
= 7.12E9 J
(1) Front-end loader, 2.5 CY [Similar to Caterpillar 936]
Fuel consumption = 4 gal/hr [Caterpiller, 1986]

((200,066 lb)/(2.60E6 lb/mo)(67 hrs/mo)
(4 gal/hr))/(55 gal/BBL)(6.28E9 J/BBL)
= 2.36E9 J
F1. Equipment for construction and demolition debris landfill closure.
Closure material: 24 inches of topsoil over 8 inches of clay over 12 inches of sand. [Estimate]
Alachua County construction and demolition landfill land surface area capped = 41 acres
B-15 crew at borrow [R. S. Means Company, 1992]
(2) Dump trucks, 16 ton
(1) Bulldozer, 200 HP
Closure material haul distance = 2 miles [Estimate]
Crew output = 75 CY/hr [R. S. Means Company, 1992]
Closure material volume = (41 A)(43,560 SF/A)
(3.6667 feet)/(27 CF/CY) = 242,540 CY
Duration = (242,540 CY)/(75 CYF/hr) = 3,234 hrs
System A_0322 landfill surface area portion
= 64.4 SF [AJ0322, E4]
(2) Dump trucks, 16 ton
Fuel consumption = 7.5 gal/hr [Estimate]
(2)(3,234 hrs)(7.5 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL)(64.4 SF)/(1,785,960 SF) = 2.00E8 J
(1) Bulldozer, 200 HP [Similar to Caterpillar 973]
Fuel consumption = 8.5 gal/hr [Caterpillar, 1986]
(3,234 hrs)(8.5 gal/hr)/(55 gal/BBL)(6.28E9 J/BBL)
(64.4 SF)/(1,785,960 SF) = 1.13E8 J
Total F1 equipment units = 9.79E9 J

G. Goods.
G1. Equipment for demolition debris placement and compaction.
Landfill equipment:
(1) Bulldozer, Caterpillar D-8
Use = 54 hours/month
(1) Front-end loader, 2.5 CY
Use = 67 hours/ month
Monthly Alachua County construction and demolition landfill debris = 2.60E6 lb
System A_0322 weight = 200,066 lb [AC0322]
(1) Bulldozer, Caterpillar D-8
Weight = 12,500 lb [Caterpillar, 1986]
Useful life = 15,000 hrs [Caterpillar, 1986]
(54 hrs/mo)/15,000 hrs)(200,066 lb)
/(2.60E6 lb/mo)(12,500 lb)(453.6 g/lb)
= 1.57E3 g
(1) Front-end loader, 2.5 CY
Weight = 21,500 lb [Estimate]
Useful life = 15,000 hrs [Caterpillar, 1986]
(67 hrs/mo)/(15,000 hrs)(200,066 lb)
/(2.60E6 lb/mo)(21,500 lb)(453.6 g/lb)
= 3.35E3 g

G1. Equipment for construction and demolition debris landfill closure.

Alachua County construction and demolition landfill land surface area capped = 41 acres
B-15 crew at borrow [R. S. Means Company, 1992]
(2) Dump trucks, 16 ton
(1) Bulldozer, 200 HP
Duration = (242,540 CY)/(75 CYF/hr) = 3,234 hrs
System A_0322 landfill surface area portion = 64.4 SF [AJ0322, E4]
(2) Dump trucks, 16 ton [AJ0322, F1]
Weight = 19,120 lb [AH0322, G1]
Useful life = 15,000 hrs [Estimate]
(2)(3,234 hrs)/(15,000 hrs)(64.4 SF)/(1,785,960 SF) (19,120 lb)(453.6 g/lb) = 1.35E2 g
(1) Bulldozer, 200 HP [AJ0322, F1]
Weight = 53,856 lb [Caterpillar, 1986]
Useful life = 10,000 hrs [Caterpillar, 1986]
(3234 hrs)/(10,000 hrs)(64.4 SF)/(1,785,960 SF) (53,856 lb)(453.6 g/lb) = 2.85E2 g

Total G1 equipment units = 5.34E3 g

G3. Materials.

Six feet high, three strand, barbed-wire fence on three sides of 41 acre Alachua County construction and demolition landfill.
Alachua County construction and demolition landfill land surface area capped = 41 acres
System A_0322 landfill surface area portion = 64.4 SF [AJ0322, E4]
Fence Length = 4,000 LF [Estimate]
Fence weight = 7.5 lb/LF [Estimate]
(4,000 LF)(7.5 lb/LF)(453.6 g/lb)(64.4 SF) /(1,785,960 SF) = 4.91E2 g

S. Services.

S1. Labor for demolition debris placement and compaction.

Alachua County construction and demolition landfill debris = 2.60E6 lb/mo
System A_0322 weight = 200,066 lb [AC0322]
Crew labor = 1,040 hours/month
Average 1990 labor salary = $6.00/hr
(1,040 hrs)($6.00/hr)(200,066 lb)/(2.60E6 lb/mo) = 4.80E2 $

S1. Labor for construction and demolition debris landfill closure.

Alachua County construction and demolition landfill land surface area capped = 41 acres
System A_0322 landfill surface area portion = 64.4 SF [AJ0322, E4]
Crew labor = $0.94/CY [R. S. Means Company, 1990]
Landfill closure volume = 242,540 CY [AJ0322, F1]
(242,540 CY)($0.94/CY)(64.4 SF)/(1,785,960 SF) = 8.22E0 $

Total S1 labor units = 4.88E2 $

S2. Labor for monitoring.

Monitoring labor = \$110,000/year in 1990 dollars

Alachua County construction and demolition landfill land surface area capped = 41 acres

System A_0322 landfill surface area portion = 64.4 SF [AJ0322, E4]

(\$110,000/yr)(64.4 SF)/(1,785,960 SF) = 3.97E0 \$/yr

TABLE F-16. AJ0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			2.23E11/yr
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	2.23E11J/yr	1	2.23E11/yr
E5	Water	NA		
F	FUEL ENERGY			5.23E15
F1	Equipment	7.92E10 J	6.60E4	5.23E15
F2	Facilities	NA		
G	GOODS			2.97E14
G1	Equipment	4.33E4 g	6.70E9	2.90E14
G2	Facilities	NA		
G3	Materials	3.97E3 g	1.80E9	7.15E12
G4	Tools	NA		
S	SERVICES			7.92E15
S1	Labor	3.96E3 $	2.00E12	7.92E15
S2	Labor	32.10 $/yr	2.00E12	6.42E13/yr

AJ0411 EMERGY INPUT CALCULATION BACK-UP

Disposal phase calculations are based on data obtained during February 11, 1992 and June 8, 1992 interviews with John H. Carter, Assistant Public Works Director, Waste Management, Alachua County Public Works Department, Gainesville, Florida.

E. Environment.

E4. Land.

Alachua County construction and demolition landfill land surface area = 40 acres

Alachua County construction and demolition landfill depth = 70 feet

Alachua County construction and demolition landfill capacity
= (40 A)(43,560 SF/A)(70 ft)/(27 CF/CY)
= 4.52E6 CY

Ratio of land surface area/CY of landfill capactiy
= (40 A)(43,560 SF/A)/(4.52E6 CY)
= 0.386 SF/CY

Compacted demolition debris weight = 1,200 lb/CY

System A_0411 weight = 1.62E6 lb [AC0411]

Calculation of A_0411 landfill surface area portion
= (1.62E6 lb)/(1,200 lb/CY)(0.386 SF/CY)
= 521 SF

Avg. net absorbed solar radiation = 110 kcal/cm^2/yr [Odum, 1990]

Annual landfill surface sunlight calculations = (Landfill surface area)(Average of insolation)
= (521 SF)(929.03 cm^2/SF)(110 kcal/cm^2/yr) (4186 J/kcla) = 2.23E11 J/yr

F. Fuel energy.

F1. Equipment for demolition debris placement and compaction.

Landfill equipment:
(1) Bulldozer, Caterpillar D-8
Use = 54 hours/month
(1) Front-end loader, 2.5 CY
Use = 67 hours/ month

Alachua County construction and demolition landfill debris = 2.60E6 lb/mo

System A_0411 weight = 1.62E6 lb [AC0411]

(1) Bulldozer, Caterpillar D-8
Fuel consumption = 15 gal/hr [Caterpillar, 1986]
((1.62E6 lb)/(2.60E6 lb/mo)(54 hrs/mo) (15 gal/hr))/(55 gal/BBL)(6.28E9 J/BBL)
= 5.76E10 J

(1) Front-end loader, 2.5 CY [Similar to Caterpillar 936]

Fuel consumption = 4 gal/hr [Caterpiller, 1986]

((1.62E6 lb)/(2.60E6 lb/mo)(67 hrs/mo)
(4 gal/hr))/(55 gal/BBL)(6.28E9 J/BBL)
= 1.91E10 J

F1. Equipment for construction and demolition debris landfill closure.
Closure material: 24 inches of topsoil over 8 inches of clay over 12 inches of sand. [Estimate]
Alachua County construction and demolition landfill land surface area capped = 41 acres
B-15 crew at borrow [R. S. Means Company, 1992]
(2) Dump trucks, 16 ton
(1) Bulldozer, 200 HP
Closure material haul distance = 2 miles [Estimate]
Crew output = 75 CY/hr [R. S. Means Company, 1992]
Closure material volume = (41 A)(43,560 SF/A)
(3.6667 feet)/(27 CF/CY) = 242,540 CY
Duration = (242,540 CY)/(75 CYF/hr) = 3,234 hrs
System A_0411 landfill surface area portion = 521 SF [AJ0411, E4]
(2) Dump trucks, 16 ton
Fuel consumption = 7.5 gal/hr [Estimate]
(2)(3,234 hrs)(7.5 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL)(521 SF)/(1,785,960 SF) = 1.62E9 J
(1) Bulldozer, 200 HP [Similar to Caterpillar 973]
Fuel consumption = 8.5 gal/hr [Caterpillar, 1986]
(3,234 hrs)(8.5 gal/hr)/(55 gal/BBL)(6.28E9 J/BBL)
(521 SF)/(1,785,960 SF) = 9.16E8 J
Total F1 equipment units = 7.92E10 J

G. Goods.

G1. Equipment for demolition debris placement and compaction.
Landfill equipment:
(1) Bulldozer, Caterpillar D-8
Use = 54 hours/month
(1) Front-end loader, 2.5 CY
Use = 67 hours/ month
Monthly Alachua County construction and demolition landfill debris = 2.60E6 lb
System A_0411 weight = 1.62E6 lb [AC0411]
(1) Bulldozer, Caterpillar D-8
Weight = 12,500 lb [Caterpillar, 1986]
Useful life = 15,000 hrs [Caterpillar, 1986]
(54 hrs/mo)/15,000 hrs)(1.62E6 lb)/(12,500 lb)
(2.60E6 lb/mo)(453.6 g/lb) = 1.27E4 g
(1) Front-end loader, 2.5 CY
Weight = 21,500 lb [Estimate]
Useful life = 15,000 hrs [Caterpillar, 1986]
(67 hrs/mo)/(15,000 hrs)(1.62E6 lb)/
(2.60E6 lb/mo)(21,500 lb)(453.6 g/lb)
= 2.72E4 g

G1. Equipment for construction and demolition debris landfill closure.

Alachua County construction and demolition landfill land surface area capped = 41 acres

B-15 crew at borrow [R. S. Means Company, 1992]

(2) Dump trucks, 16 ton

(1) Bulldozer, 200 HP

Duration = (242,540 CY)/(75 CYF/hr) = 3,234 hrs

System A_0411 landfill surface area portion = 521 SF [AJ0411, E4]

(2) Dump trucks, 16 ton [AJ0322, F1]

Weight = 19,120 lb [AH0322, G1]

Useful life = 15,000 hrs [Estimate]

(2)(3,234 hrs)/(15,000 hrs)(521 SF)/(1,785,960 SF)
(19,120 lb)(453.6 g/lb) = 1.09E3 g

(1) Bulldozer, 200 HP [AJ0322, F1]

Weight = 53,856 lb [Caterpillar, 1986]

Useful life = 10,000 hrs [Caterpillar, 1986]

(3,234 hrs)/(10,000 hrs)(521 SF)/(1,785,960 SF)
(53,856 lb)(453.6 g/lb) = 2.31E3 g

Total G1 equipment units = 4.33E4 g

G3. Materials.

Six feet high, three strand, barbed-wire fence on three sides of 41 acre Alachua County construction and demolition landfill.

Alachua County construction and demolition landfill land surface area capped = 41 acres

System A_0411 landfill surface area portion = 521 SF [AJ0411, E4]

Fence Length = 4,000 LF [Estimate]

Fence weight = 7.5 lb/LF [Estimate]

(4,000 LF)(7.5 lb/LF)(453.6 g/lb)(521 SF)
/(1,785,960 SF) = 3.97E3 g

S. Services.

S1. Labor for demolition debris placement and compaction.

Alachua County construction and demolition landfill debris = 2.60E6 lb/mo

System A_0411 weight = 1.62E6 lb [AC0411]

Crew labor = 1,040 hours/month

Average 1990 labor salary = $6.00/hr

(1,040 hrs)($6.00/hr)(1.62E6 lb)/(2.60E6 lb/mo)
= 3.89E3 $

S1. Labor for construction and demolition debris landfill closure.

Alachua County construction and demolition landfill land surface area capped = 41 acres

System A_0411 landfill surface area portion = 521 SF [AJ0411, E4]

Crew labor = $0.94/CY [R. S. Means Company, 1990]

Landfill closure volume = 242,540 CY [AJ0322, F1]

(242,540 CY)($0.94/CY)(521 SF)/(1,785,960 SF)
= 6.65E1 $

Total S1 labor units = 3.96E3 $

S2. Labor for monitoring.

Monitoring labor = $110,000/year in 1990 dollars

Alachua County construction and demolition landfill land surface area capped = 41 acres

System A_0411 landfill surface area portion = 521 SF [AJ0411, E4]

($110,000/yr)(521 SF)/(1,785,960 SF) = 3.21E1 $/yr

TABLE F-17. BC0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT	[RE: CALCULATION BACK-UP]		6.46E16
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY	[RE: CALCULATION BACK-UP]		8.03E16
F1	Equipment	NA		
F2	Facilities	NA		
G	GOODS	[RE: CALCULATION BACK-UP]		6.86E15
G1	Equipment	NA		
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES	[RE: CALCULATION BACK-UP]		2.26E16
S1	Labor	NA		

BC0322 EMERGY INPUT CALCULATION BACK-UP

Steel transformity = 1.80E9 SEJ/g
Petroleum product transformity = 6.60E4 SEJ/J
[Appendix D]
Steel quantity = 9.49E7 g [Material take-off]
Petroleum product quantity = (9.49E7 g)(2%) = 1.90E6 g
(1.90E6 g)/((9 lb/Gal)(55 Gal/BBL)(453.6 g/lb))
(6.28E9 J/BBL) = 5.30E10 J

E. Environment.
Steel
Environmental input transformity portion = 37.3 %
[Odum, in press]
(1.80E9 sej/g)(0.373) = 6.71E8 sej/g
(9.49E7 g)(6.71E8 sej/g) = 6.37E16 sej
Petroleum product
Environmental input transformity portion = 25 %
[Estimate]
(6.60E4 sej/J)(0.25) = 1.65E4 sej/J
(5.30E10 J)(1.65E4 sej/J) = 8.75E14 sej

Total environmental input = 6.46E16 sej

F. Fuel energy.
Steel
Fuel energy input transformity portion = 46.5 %
[Odum, in press]
(1.80E9 sej/g)(0.465) = 8.37E8 sej/g
(9.49E7 g)(8.37E8 sej/g) = 7.94E16 sej
Petroleum product
Fuel energy input transformity portion = 25 %
[Estimate]
(6.60E4 sej/J)(0.25) = 1.65E4 sej/J
(5.30E10 J)(1.65E4 sej/J) = 8.75E14 sej

Total fuel energy input = 8.03E16 sej

G. Goods.
Steel
Goods input transformity portion = 3.5 %
[Odum, in press]
(1.80E9 sej/g)(0.035) = 6.30E7 sej/g
(9.49E7 g)(6.30E7 SEJ/g) = 5.98E15 sej
Petroleum product
Goods input transformity portion = 25 %
[Estimate]
(6.60E4 sej/J)(0.25) = 1.65E4 sej/J
(5.30E10 J)(1.65E4 sej/J) = 8.75E14 sej

Total goods input = 6.86E15 sej

S. Services.

Steel

Services input transformity portion = 12.7 %

[Odum, in press]

(1.80E9 sej/g)(0.127) = 2.29E8 sej/g

(9.49E7 g)(2.29E8 sej/g) = 2.17E16 sej

Petroleum product

Services input transformity portion = 25 %

[Estimate]

(6.60E4 sej/J)(0.25) = 1.65E4 sej/J

(5.30E10 J)(1.65E4 sej/J) = 8.75E14 sej

Total services input = 2.26E16 sej

TABLE F-18. BC0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT	[RE: CALCULATION BACK-UP]		1.98E16
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY	[RE: CALCULATION BACK-UP]		1.47E17
F1	Equipment	NA		
F2	Facilities	NA		
G	GOODS	[RE: CALCULATION BACK-UP]		4.42E15
G1	Equipment	NA		
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES	[RE: CALCULATION BACK-UP]		6.11E16
S1	Labor	NA		

BC0411 EMERGY INPUT CALCULATION BACK-UP

Steel transformity = 1.80E9 sej/g
Concrete transformity = 2.40E8 sej/g
Petroleum product transformity = 6.60E4 sej/J
Wood transformity = 3.49E4 sej/J
[Appendix D]
Steel quantity = 1.96E7 g [Material take-off]
Concrete quantity = 7.89E8 g [Material take-off]
Petroleum product quantity = 1.99E10 J
[Material take-off]
Wood quantity = 1.80E11 g [Material take-off]

E. Environment.

Steel

Environmental input transformity portion = 37.3 %
[Odum, in press]
(1.80E9 sej/g)(0.373) = 6.71E8 sej/g
(1.96E7 g)(6.71E8 sej/g) = 1.32E16 sej

Concrete

Environmental input transformity portion = 1 %
[Brown & McClanahan, 1992]
(2.40E8 sej/g)(0.01) = 2.40E6 sej/g
(7.89E8 g)(2.40E6 sej/g) = 1.89E15 sej

Petroleum product

Environmental input transformity portion = 25 %
[Estimate]
(6.60E4 sej/J)(0.25) = 1.65E4 sej/J
(1.99E10 J)(1.65E4 sej/J) = 3.28E14 sej

Wood

Environmental input transformity portion = 69.5 %
[Odum, in press]
(3.49E4 sej/J)(0.695) = 2.43E4 sej/J
(1.80E11 J)(2.43E4 sej/J) = 4.37E15 sej

Total environmental input = 1.98E16 sej

F. Fuel energy.

Steel

Fuel energy transformity portion = 46.5 %
[Odum, in press]
(1.80E9 sej/g)(0.465) = 8.37E8 sej/g
(1.96E7 g)(8.37E8 sej/g) = 1.64E16 sej

Concrete

Fuel energy input transformity portion = 68.8 %
[Brown & McClanahan, 1992]
(2.40E8 sej/g)(0.688) = 1.65E8 sej/g
(7.89E8 g)(1.65E8 sej/g) = 1.30E17 sej

Petroleum product

Fuel energy input transformity portion = 25 %
[Estimate]
(6.60E4 sej/J)(0.25) = 1.65E4 sej/J
(1.99E10 J)(1.65E4 sej/J) = 3.28E14 sej

Wood

Fuel energy input transformity portion = 0.7 %

[Doherty, Odum, & Nilsson, 1992]

(3.49E4 sej/J)(0.007) = 2.44E2 sej/J

(1.80E11 J)(2.44E2 sej/J) = 4.39E13 sej

Total fuel energy input = 1.47E17 sej

G. Goods.

Steel

Goods input transformity portion = 3.5 %

[Odum, in press]

(1.80E9 sej/g)(0.035) = 6.30E7 sej/g

(1.96E7 g)(6.30E7 sej/g) = 1.24E15 sej

Concrete

Goods input transformity portion = 1.5 %

[Brown & McClanahan, 1992]

(2.40E8 sej/g)(0.015) = 3.60E6 sej/g

(7.89E8 g)(3.60E6 sej/g) = 2.84E15 sej

Petroleum product

Goods input transformity portion = 25 %

[Estimate]

(6.60E4 sej/J)(0.25) = 1.65E4 sej/J

(1.99E10 J)(1.65E4 sej/J) = 3.28E14 sej

Wood

Goods input transformity portion = 0.2 %

[Doherty, Odum, & Nilsson, 1992]

(3.49E4 sej/J)(0.002) = 6.98E1 sej/J

(1.80E11 J)(6.98E1 sej/J) = 1.26E13 sej

Total goods input = 4.42E15 sej

S. Services.

Steel

Services input transformity portion = 12.7 %

[Odum, in press]

(1.80E9 sej/g)(0.127) = 2.29E8 sej/g

(1.96E7 g)(2.29E8 sej/g) = 4.49E15 sej

Concrete

Services input transformity portion = 28.7 %

[Brown & McClanahan, 1992]

(2.40E8 sej/g)(0.287) = 6.89E7 sej/g

(7.89E8 g)(6.89E7 sej/g) = 5.44E16 sej

Petroleum product

Services input transformity portion = 25 %

[Estimate]

(6.60E4 sej/J)(0.25) = 1.65E4 sej/J

(1.99E10 J)(1.65E4 sej/J) = 3.28E14 sej

Wood

Services input transformity portion = 29.6 %

[Doherty, Odum, & Nilsson, 1992]

(3.49E4 sej/J)(0.296) = 1.03E4 sej/J

(1.80E11 J)(1.03E4 sej/J) = 1.85E15 sej

Total services input = 6.11E16 sej

TABLE F-19. BD0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			1.44E13
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	1.47E10 J	1	1.47E10
E5	Water	2.16E7 J	6.66E5	1.44E13
F	FUEL ENERGY			1.50E14
F1	Equipment	NA		
F2	Facilities	9.46E8 J	1.59E5	1.50E14
G	GOODS			0
G1	Equipment	NA		
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES			4.64E15
S1	Labor	2.32E3 $	2.00E12	4.64E15

BD0322 EMERGY INPUT CALCULATION BACK-UP

E. Environment.

E4. Land.

Design facility ground floor area = 5200 SF [Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]

Project portion of facility use = 20% [Estimate]

Project design duration = 14 months + 100 hours or 0.5 months for redesign of system 0322/VE study

System 0322 portion of total project = \$100,903/\$3,702,083 = 0.02726 [Project Time & Cost, Inc., 1988]

Land surface sunlight calculations:

(Facility ground area)(Average of insolation)

Avg. net absorbed solar radiation = 110 kcal/cm^2/yr [Odum, 1990]

(5200 SF)(929.03 cm^2/SF)(110 kcal/cm^2/yr)(0.20) (14.5 mo/12 mo/yr)(0.02726)(4186 J/kcal) = 1.47E10 J

E5. Water.

Project design budget = 5568 hours + 100 hours

Total 1991 design phase water consumption = 791,000 gal [Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]

Total 1991 design phase labor = 101,121 hours [Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]

Water consumption/labor hr = 791,000 gal/101,121 hrs = 7.8 gal/hr

Gibbs free energy in water = 4.94 J/g [Odum, 1990]

(5668 hr)(0.02726)(7.8 gal/hr)(8 lb/gal)(453.6 g/lb) (4.94 J/g) = 2.16E7 J

F. Fuel energy.

F2. Facility.

Project design budget = 5568 hours + 100 hours

Total 1991 design phase electric consumption = 172,200 kWh [Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]

Total 1991 design phase labor = 101,121 hours [Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]

Electric consumption/labor hr = 172,200 kWh/101,121 hrs = 1.7 kWh/hr

(5668 hr)(0.02726)(1.7 kWh/hr)(3.60E6 J/kWh) = 9.46E8 J

G. Goods.

Not available. Use input = 0.

S. Services.

S1. Labor.

Project design labor budget = \$83,700

(\$83,700)(5668 hr/5568 hr)(0.02726) = 2.32E3 \$

TABLE F-20. BD0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			2.08E13
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	2.09E10 J	1	2.09E10
E5	Water	3.12E7 J	6.66E5	2.08E13
F	FUEL ENERGY			2.18E14
F1	Equipment	NA		
F2	Facilities	1.37E9 J	1.59E5	2.18E14
G	GOODS			0
G1	Equipment	NA		
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES			6.70E15
S1	Labor	3.35E3 $	2.00E12	6.70E15

BD0411 EMERGY INPUT CALCULATION BACK-UP

E. Environment.

E4. Land.

Design facility ground floor area = 5200 SF [Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]

Project portion of facility use = 20% [Estimate]

Project design duration = 14 months + 160 hours or 0.5 months for redesign of system 0411/VE study

System 0322 portion of total project = \$144,193/\$3,702,083 = 0.03895 [Project Time & Cost, Inc., 1988]

Land surface sunlight calculations:
(Facility ground area)(Average of insolation)

Avg. net absorbed solar radiation = 110 kcal/cm^2/yr [Odum, 1990]

(5200 SF)(929.03 cm^2/SF)(110 kcal/cm^2/yr)(0.20)
(14.5 mo/12 mo/yr)(0.03895)(4186 J/kcal) = 2.09E10 J

E5. Water.

Project design budget = 5568 hours + 160 hours

Total 1991 design phase water consumption = 791,000 gal [Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]

Total 1991 design phase labor = 101,121 hours [Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]

Water consumption/labor hr = 791,000 gal/101,121 hrs = 7.8 gal/hr

Gibbs free energy in water = 4.94 J/g [Odum, 1990]

(5728 hr)(0.03895)(7.8 gal/hr)(8 lb/gal)(453.6 g/lb)
(4.94 J/g) = 3.12E7 J

F. Fuel energy.

F2. Facility.

Project design budget = 5568 hours + 160 hours

Total 1991 design phase electric consumption = 172,200 kWh [Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]

Total 1991 design phase labor = 101,121 hours [Rogers, Lovelock,& Fritz, Inc., Winter Park, Florida]

Electric consumption/labor hr = 172,200 kWh/101,121 hrs = 1.7 kWh/hr

(5728 hr)(0.03895)(1.7 kWh/hr)(3.60E6 J/kWh)
= 1.37E9 J

G. Goods.

Not available. Use input = 0.

S. Services.

S1. Labor.

Project design labor budget = \$83,700

(\$83,700)(5728 hr/5568 hr)(0.03895) = 3.35E3 \$

TABLE F-21. BE0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY			3.30E15
F1	Equipment	5.00E10 J	6.60E4	3.30E15
F2	Facilities	NA		
G	GOODS			3.50E15
G1	Equipment	NA		
G2	Facilities	NA		
G3	Materials	5.30E10 J	6.60E4	3.50E15
G4	Tools	NA		
S	SERVICES			2.52E16
S1	Labor	1.26E4 $	2.00E12	2.52E16

BE0322 EMERGY INPUT CALCULATION BACK-UP

E. Environment.

Not available. Use input = 0.

F. Fuel energy.

F1. Equipment.

Flat-bed transports (20 ton maximum)

Total system 0322 weight = 209,200 lb [Material take-off]

(209,200 lb)/(2000 lb/ton)/(20 ton/transport) = 6 transports

System 0322 to Homestead Air Force Base, FL from Stark, FL & return = 365 miles

Transport fuel consumption = 5 mpg [Estimate]

(6)(365 mi)/(5mpg)/(55 gal/BBL)(6.28E9 J/BBL) = 5.00E10 J

G. Goods.

G3. Materials.

Petroleum Product, structural steel paint

Total system 0322 wt. = (209,200 lb)(453.6 g/lb) = 9.49E7 g

Structural steel paint wt. = 2% of system wt.

(9.49E7 g)(0.02)/(2.25E5 g/BBL)(6.28E9 J/BBL) = 5.30E10 J

S. Services.

S1. Labor.

System 0322 output = 200 ton/week [Estimate]

Labor hours/200 tons = 4005 hours [Estimate]

Average 1989 system 0322 labor salary =$6/hr [Estimate]

(200 ton/wk)(2000 lb/ton)/(4005 hours/week) = 100 lb/hour

(209,200 lb)/(100 lb/hour)($6.00/hour) = 1.26E4 $

TABLE F-22. BE0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere			
E2	Ecol. Prod.			
E3	Energy			
E4	Land			
E5	Water			
F	FUEL ENERGY			0
F1	Equipment			
F2	Facilities			
G	GOODS			0
G1	Equipment			
G2	Facilities			
G3	Materials			
G4	Tools			
S	SERVICES			0
S1	Labor			

BE0411 EMERGY INPUT CALCULATION BACK-UP

All EMERGY inputs = 0 because component production of concrete tilt-up panels takes place during construction phase F.

TABLE F-23. BF0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY			6.67E15
F1	Equipment	1.01E11 J	6.60E4	6.67E15
F2	Facilities	NA		
G	GOODS			1.10E15
G1	Equipment	1.64E5 g	6.70E9	1.10E15
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES			2.96E16
S1	Labor	1.48E4 $	2.00E12	2.96E16

BF0322 EMERGY INPUT CALCULATION BACK-UP

E. Environment.
Not available. Use input = 0.

F. Fuel energy.
F1. Equipment.
F1A. At open-web joists. [Same as AF0322]
F1B. At metal decking. [Same as AF0322]
Total F1A & F1B equipment units = 9.84E10 J
F1C. At additional structural steel.
Columns (4) W 12X45 X 30'-0" = 120 LF
(4) W 10X33 X 30'-0" = 120 LF
[Hanscomb Associates, Inc., 1986]
E-2 crew [R. S. Means Company, 1992]
Crew output = 129 LF/hr
(240 LF)/(129 LF/hr) = 2 hrs
(1) Crane, 90 ton
Fuel consumption = 5 gal/hr
[Estimate]
(2 hrs)(5 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) =1.14E9 J
Beams (6) W 24X55 X 30'-0" = 180 LF
[Hanscomb Associates, Inc., 1986]
E-5 crew [R. S. Means Company, 1992]
Crew output = 138.5 LF/hr
(180 LF)/(138.5 LF/hr) = 1.5 hrs
(1) Crane, 90 ton
Fuel consumption = 5 gal/hr
[Estimate]
(1.5 hrs)(5 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) =8.56E8 J
(1) Welding machine, gas
Fuel consumption = 5 gal/hr
[Estimate]
(1.5 hrs)(5 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) =8.56E8 J
Total F1 equipment units = 1.01E11 J

G. Goods.
G1. Equipment.
G1A. At open-web joists. [Same as AF0322]
(1) Crane, 90 ton = 1.48E5 g
(2) Welding machines, gas = 1.43E3 g
G1B. At metal decking. [Same as AF0322]
(1) Welding machine, gas = 1.59E3 g
G1C. At additional structural steel.
Columns.
(1) Crane, 90 ton
Weight = 156,000 lb [Estimate]
Useful life = 20,000 hrs [Estimate]
Use = 2 hrs [BF0322, F1C]
(2hrs)/(20,000 hrs)(156,000 lb)
(453.6 g/lb) = 7.08E3 g

Beams.

(1) Crane, 90 ton

Weight = 156,000 lb [Estimate]
Useful life = 20,000 hrs [Estimate]
Use = 1.5 hrs [BF0322, F1C]
(1.5 hrs)/(20,000 hrs)(156,000 lb)
(453.6 g/lb) = 5.31E3 g

(1) Welding machine, gas

Weight = 2,000 lb [Estimate]
Useful life = 20,000 hrs [Estimate]
Use = 1.5 hrs [BF0322, F1C]
(1.5 hrs)/(20,000 hrs)(2,000 lb)
(453.6 g/lb) = 6.80E1 g

Total G1 equipment units = 1.64E5 g

S. Services.

S1. Labor.

S1A. At open-web joists. [Same as AF0322]
= $9948

S1B. At metal decking. [Same as AF0322]
= $4208

S1C. At additional structural steel.

Columns = 240 LF [BF0322, F1C]
Crew labor = $1.25/LF
[R. S. Means Company, 1990]
(240 LF)($1.25/LF) = $300

Beams =180 LF [BF0322, F1C]
Crew labor = $1.68/LF
[R. S. Means Company, 1990]
(180 LF)($1.68/LF) = $302

Total S1 labor units = 1.48E4 $

TABLE F-24. BF0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY			2.41E15
F1	Equipment	3.65E10 J	6.60E4	2.41E15
F2	Facilities	NA		
G	GOODS			5.89E14
G1	Equipment	8.79E4 g	6.70E9	5.89E14
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES			5.60E16
S1	Labor	2.80E4 $	2.00E12	5.60E16

BF0411 EMERGY INPUT CALCULATION BACK-UP

E. Environment.
E5. Water included in concrete transformity phases A-C. [BC0411, E]

F. Fuel energy.
F1. Equipment.
C-14 crew [R. S. Means Company, 1992]
Crew output = 264.4 SF/hr
Concrete tilt-up panel area = 19,189 SF [Material take-off]
(19,189 SF)/(264.4 SF/hr) = 72.6 hrs
(1) Crane, 80 ton
Fuel consumption = 5 gal/hr [Estimate]
Use = 20% of output hours [Estimate]
(72.6 hrs)(0.20)(5 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 8.29E9 J
(2) Finishing machines, gas
Fuel consumption = 2 gal/hr [Estimate]
Use = 20% of output hours [Estimate]
(2)(72.6 hrs)(0.20)(2 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 3.32E9 J
(2) Trucks, concrete transport
Fuel consumption = 7.5 gal/hr [Estimate]
Use = 20% of output hours [Estimate]
(2)(72.6 hrs)(0.20)(7.5 gal/hr)/
(55 gal/BBL)(6.28E9 J/BBL) = 2.49E10 J
Total F1 equipment units = 3.65E10 J

G. Goods.
G1. Equipment.
(1) Crane, 80 ton [BF0411, F1]
Weight = 100,000 lb [Estimate]
Useful life = 20,000 hrs [Estimate]
Use = 20% of output hours [Estimate]
(72.6 hrs)(0.20)/(20,000 hrs)(100,000 lb)
(453.6 g/lb) = 3.29E4 g
(2) Finishing machines, gas [BF0411, F1]
Weight = 400 lb [Estimate]
Useful life = 10,000 hrs [Estimate]
Use = 20% of output hours [Estimate]
(2)(72.6 hrs)(0.20)/(10,000 hrs)(400 lb)
(453.6 g/lb) = 5.26E2 g
(2) Trucks, concrete transport [BF0411, F1]
Weight = 62,000 lb [Rinker Materials Corp.]
Useful life = 15,000 hrs [Estimate]
Use = 20% of output hours [Estimate]
(2)(72.6 hrs)(0.20)/(15,000 hrs)(62,000 lb)
(453.6 g/lb) = 5.45E4 g
Total G1 equipment units = 8.79E4 g

S. Services.

S1. Labor.

C-14 crew [R. S. Means Company, 1990]

Concrete tilt-up panel labor = $1.43/SF [R. S. Means Company, 1990]

Concrete tilt-up panel area = 19,189 SF [Material take-off]

(19,189 SF)($1.43/SF) = $27,440

(2) Truck drivers, concrete transport

Driver labor = $18.10/hr [R. S. Means Company, 1990]

Driver labor hours = 20% of output hours [Estimate]

(2)(72.6 hrs)(0.20)($18.10/hr) = $526

Total S1 labor units = 2.80E4 $

TABLE F-25. BG0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere			
E2	Ecol. Prod.			
E3	Energy			
E4	Land			
E5	Water			
F	FUEL ENERGY			0
F1	Equipment			
F2	Facilities			
G	GOODS			0
G1	Equipment			
G2	Facilities			
G3	Materials			
G4	Tools			
S	SERVICES			0
S1	Labor			

BG0322 EMERGY INPUT CALCULATION BACK-UP

E. Environment.

Environment input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0322 of alternative B did not require environment input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Replacement.
5. Repair.

Environment input = 0.

F. Fuel energy.

Fuel energy input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0322 of alternative B did not require fuel energy input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Replacement.
5. Repair.

Fuel energy input = 0.

G. Goods.

Goods input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0322 of alternative B did not require goods input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Replacement.

   5. Repair.

Goods input = 0.

S. Services.

Services input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0322 of alternative B did not require services input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Replacement.
5. Repair.

Services input = 0.

TABLE F-26. BG0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY			2.41E13
F1	Equipment	3.65E8 J	6.60E4	2.41E13
F2	Facilities	NA		
G	GOODS			2.41E14
G1	Equipment	NA		
G2	Facilities	NA		
G3	Materials	3.65E9 J	6.60E4	2.41E14
G4	Tools	NA		
S	SERVICES			5.12E15
S1	Labor	2.56E3 $	2.00E12	5.12E15

BG0411 EMERGY INPUT CALCULATION BACK-UP

E. Environment.

Environment input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0322 of alternative B did not require environment input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Replacement.
5. Repair.

Environment input = 0.

F. Fuel energy.

Fuel energy input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0322 of alternative B did not require fuel energy input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Repair.

Concrete tilt-up panel control joints are replaced every 20 years. Fuel energy input calculations for replacement follow:

F1. Equipment.

(2) Vehicles [Estimate]

Fuel consumption = 15 mpg
Trip distance = 48 miles [Estimate]
Number of trips = 2 [Estimate]
Trip portion to BG0411 = 50%
(2)(48 mi)(2 trips)/(15 mpg) = 6.4 gal
(6.4 gal)/(55 gal/BBL)(6.28E9 J/BBL)(0.5)
= 3.65E8 J

Total F1 equipment units = 3.65E8 J.

G. Goods.

Goods input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0322 of alternative B did not require goods input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Repair.

Concrete tilt-up panel control joints are replaced every 20 years. Goods input calculations for replacement follow:

G3. Materials.

Petroleum product, control joint

Quantity = 32 gal [Material take-off]

(32 gal)/(55 gal/BBL)(6.28E9 J/BBL)
= 3.65E9 J

Total G3 materials units = 3.65E9 J.

S. Services.

Services input EMERGY for the following use phase items were not available for the government project case study application:

1. Financing.
2. Tax elements.
3. Insurance.

System 0322 of alternative B did not require services input EMERGY for the following items during the analysis period:

1. Maintenance.
2. Operation.
3. Alteration.
4. Repair.

Concrete tilt-up panel control joints are replaced every 20 years. Services input calculations for replacement follow:

S1. Labor.

S1A. Removal of existing control joint.

Quantity = 2439 LF [Material take-off]
Labor = $0.75/LF [Estimate]

(2439 LF)($0.75/LF) = $1830

S1B. Placement of new control joint.

Quantity = 2439 LF [Material take-off]
Labor = $0.30/LF
[R. S. Means Company, 1990]
(2439 LF)($0.30/LF) = $732

Total S1 labor units = 2.56E3 $

TABLE F-27. BH0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY			3.21E16
F1	Equipment	4.86E11 J	6.60E4	3.21E16
F2	Facilities	NA		
G	GOODS			4.76E15
G1	Equipment	7.11E5 g	6.70E9	4.76E15
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES			5.56E16
S1	Labor	2.78E4 $	2.00E12	5.56E16

BH0322 EMERGY INPUT CALCULATION BACK-UP

E. Environment.
Not available. Use input = 0.

F. Fuel energy.
F1. Equipment.
B-8 crew [R. S. Means Company, 1992]
(2) Dump trucks, 16 ton
(1) Front-end loader, 2.5 CY
(1) Hydraulic crane, 25 ton
Demolition output = 2500 CF/hr
[R. S. Means Company, 1992]
Building volume = 925,000 CF
[Architectural drawings]
System 0211 portion of demolition = 25%
System 0322 portion of demolition = 50%
System 0411 portion of demolition = 25%
[Estimate]
Duration = (925,000 CF)/(2500 CF/hr)(0.5) = 185 hrs
(2) Dump trucks, 16 ton
Fuel consumption = 7.5 gal/hr [Estimate]
(2)(185 hrs)(7.5 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 3.17E11 J
(1) Front-end loader, 2.5 CY [Caterpillar 936]
Fuel consumption = 4 gal/hr
[Caterpiller, 1986]
(185 hrs)(4 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 8.45E10 J
(1) Hydraulic crane, 25 ton
Fuel consumption = 4 gal/hr [Estimate]
(185 hrs)(4 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 8.45E10 J
Total F1 equipment units = 4.86E11 J

G. Goods.
G1. Equipment.
B-8 crew [R. S. Means Company, 1992]
Duration = 185 hrs [AH0322, F1]
(2) Dump trucks, 16 ton
Weight = 19,120 lb
[Waste Management, Alachua County
Public Works Department,
Gainesville, Florida]
Useful life = 15,000 hrs [Estimate]
(2)(185 hrs)/(15,000 hrs)(19,120 lb)
(453.6 g/lb) = 2.14E5 g
(1) Front-end loader, 2.5 CY [Caterpillar 936]
Weight = 26,600 lb [Caterpiller, 1986]
Useful life = 10,000 hrs [Caterpiller, 1986]
(185 hrs)/(10,000 hrs)(26,600 lb)
(453.6 g/lb) = 2.23E5 g
(1) Hydraulic crane, 25 ton
Weight = 48,987 lb [Link-Belt HSP-8025S]

Useful life = 15,000 hrs [Estimate]
(185 hrs)/(15,000 hrs)(48,987 lb)
(453.6 g/lb) = 2.74E5 g
Total G1 equipment units = 7.11E5 g

S. Services.
S1. Labor.
B-8 crew [R. S. Means Company, 1992]
Crew labor = $0.06/CF [R. S. Means Company, 1990]
Building volume = 925,000 CF
[Architectural drawings]
System 0322 portion of demolition = 50%
(925,000 CF)($0.06/CF)(0.50) = $27,750
Total S1 labor units = 2.78E4 $

TABLE F-28. BH0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	NA		
E5	Water	NA		
F	FUEL ENERGY			2.81E16
F1	Equipment	4.26E11 J	6.60E4	2.81E16
F2	Facilities	NA		
G	GOODS			4.17E15
G1	Equipment	6.23E5 g	6.70E9	4.17E15
G2	Facilities	NA		
G3	Materials	NA		
G4	Tools	NA		
S	SERVICES			4.92E16
S1	Labor	2.46E4 $	2.00E12	4.92E16

BH0411 EMERGY INPUT CALCULATION BACK-UP

E. Environment.
Not available. Use input = 0.

F. Fuel energy.
F1. Equipment.
B-8 crew for concrete tilt-up panel walls
[R. S. Means Company, 1992]
(2) Dump trucks, 16 ton
(1) Front-end loader, 2.5 CY
(1) Hydraulic crane, 25 ton
Demolition output = 1900 CF/hr
[R. S. Means Company, 1992]
Building volume = 925,000 CF
[Architectural drawings]
System 0211 portion of demolition = 33 1/3%
System 0322 portion of demolition = 33 1/3%
System 0411 portion of demolition = 33 1/3%
[Estimate]
Duration = (925,000 CF)/(2500 CF/hr)(0.333)
= 162 hrs
(2) Dump trucks, 16 ton
Fuel consumption = 7.5 gal/hr [Estimate]
(2)(162 hrs)(7.5 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 2.78E11 J
(1) Front-end loader, 2.5 CY [Caterpillar 936]
Fuel consumption = 4 gal/hr
[Caterpiller, 1986]
(162 hrs)(4 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 7.40E10 J
(1) Hydraulic crane, 25 ton
Fuel consumption = 4 gal/hr [Estimate]
(162 hrs)(4 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL) = 7.40E10 J
Total F1 equipment units = 4.26E11 J

G. Goods.
G1. Equipment.
B-8 crew [R. S. Means Company, 1992]
Duration = 162 hrs [AH0322, F1]
(2) Dump trucks, 16 ton
Weight = 19,120 lb
[Waste Management, Alachua County Public Works Department, Gainesville, Florida]
Useful life = 15,000 hrs [Estimate]
(2)(162 hrs)/(15,000 hrs)(19,120 lb)
(453.6 g/lb) = 1.87E5 g
(1) Front-end loader, 2.5 CY [Caterpillar 936]
Weight = 26,600 lb [Caterpiller, 1986]
Useful life = 10,000 hrs [Caterpiller, 1986]
(162 hrs)/(10,000 hrs)(26,600 lb)
(453.6 g/lb) = 1.96E5 g

(1) Hydraulic crane, 25 ton
Weight = 48,987 lb [Link-Belt HSP-8025S]
Useful life = 15,000 hrs [Estimate]
(162 hrs)/(15,000 hrs)(48,987 lb)
(453.6 g/lb) = 2.40E5 g
Total G1 equipment units = 6.23E5 g

S. Services.
S1. Labor.
B-8 crew [R. S. Means Company, 1992]
Crew labor = $0.08/CF [R. S. Means Company, 1990]
Building volume = 925,000 CF
[Architectural drawings]
System 0322 portion of demolition = 33 1/3%
(925,000 CF)($0.08/CF)(0.333) = $24,642
Total S1 labor units = 2.46E4 $

TABLE F-29. BI0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere			
E2	Ecol. Prod.			
E3	Energy			
E4	Land			
E5	Water			
F	FUEL ENERGY			0
F1	Equipment			
F2	Facilities			
G	GOODS			0
G1	Equipment			
G2	Facilities			
G3	Materials			
G4	Tools			
S	SERVICES			0
S1	Labor			

BI0322 EMERGY INPUT CALCULATION BACK-UP

All EMERGY inputs equal zero because alternative B assumes no recycling of demolition debris.

TABLE F-30. BI0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			0
E1	Atmosphere			
E2	Ecol. Prod.			
E3	Energy			
E4	Land			
E5	Water			
F	FUEL ENERGY			0
F1	Equipment			
F2	Facilities			
G	GOODS			0
G1	Equipment			
G2	Facilities			
G3	Materials			
G4	Tools			
S	SERVICES			0
S1	Labor			

BI0411 EMERGY INPUT CALCULATION BACK-UP

All EMERGY inputs equal zero because alternative B assumes no recycling of demolition debris.

TABLE F-31. BJ0322.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			2.88E10/yr
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	2.88E10J/yr	1	2.88E10/yr
E5	Water	NA		
F	FUEL ENERGY			6.73E14
F1	Equipment	1.02E10 J	6.60E4	6.73E14
F2	Facilities	NA		
G	GOODS			3.84E13
G1	Equipment	5.59E3 g	6.70E9	3.75E13
G2	Facilities	NA		
G3	Materials	5.13E2 g	1.80E9	9.23E11
G4	Tools	NA		
S	SERVICES			1.02E15
S1	Labor	5.11E2 $	2.00E12	1.02E15
S2	Labor	4.15 $/yr	2.00E12	8.30E12/yr

BJ0322 EMERGY INPUT CALCULATION BACK-UP

Disposal phase calculations are based on data obtained during February 11, 1992 and June 8, 1992 interviews with John H. Carter, Assistant Public Works Director, Waste Management, Alachua County Public Works Department, Gainesville, Florida.

E. Environment.

E4. Land.

Alachua County construction and demolition landfill land surface area = 40 acres

Alachua County construction and demolition landfill depth = 70 feet

Alachua County construction and demolition landfill capacity
= (40 A)(43,560 SF/A)(70 ft)/(27 CF/CY)
= 4.52E6 CY

Ratio of land surface area/CY of landfill capactiy
= (40 A)(43,560 SF/A)/(4.52E6 CY)
= 0.386 SF/CY

Compacted demolition debris weight = 1,200 lb/CY

System B_0322 weight = 209,200 lb [BC0322]

Calculation of B_0322 landfill surface area portion
= (209,200 lb)/(1,200 lb/CY)(0.386 SF/CY)
= 67.3 SF

Avg. net absorbed solar radiation = 110 kcal/cm^2/yr [Odum, 1990]

Annual landfill surface sunlight calculations =
(Landfill surface area)(Average of insolation)
= (67.3 SF)(929.03 cm^2/SF)(110 kcal/cm^2/yr)
(4186 J/kcal) = 2.88E10 J/yr

F. Fuel energy.

F1. Equipment for demolition debris placement and compaction.

Landfill equipment:
(1) Bulldozer, Caterpillar D-8
Use = 54 hours/month
(1) Front-end loader, 2.5 CY
Use = 67 hours/ month

Alachua County construction and demolition landfill debris = 2.60E6 lb/mo

Compacted demolition debris weight = 1,200 lb/CY

System B_0322 weight = 209,200 lb [BC0322]

(1) Bulldozer, Caterpillar D-8
Fuel consumption = 15 gal/hr [Caterpillar, 1986]
((209,200 lb)/(2.60E6 lb/mo)(54 hrs/mo)
(15 gal/hr))/(55 gal/BBL)(6.28E9 J/BBL)
= 7.44E9 J

(1) Front-end loader, 2.5 CY [Similar to Caterpillar 936]
Fuel consumption = 4 gal/hr [Caterpiller, 1986]

((209,200 lb)/(2.60E6 lb/mo)(67 hrs/mo)
(4 gal/hr))/(55 gal/BBL)(6.28E9 J/BBL)
= 2.46E9 J

F1. Equipment for construction and demolition debris landfill closure.

Closure material: 24 inches of topsoil over 8 inches of clay over 12 inches of sand. [Estimate]
Alachua County construction and demolition landfill land surface area capped = 41 acres
B-15 crew at borrow [R. S. Means Company, 1992]
(2) Dump trucks, 16 ton
(1) Bulldozer, 200 HP
Closure material haul distance = 2 miles [Estimate]
Crew output = 75 CY/hr [R. S. Means Company, 1992]
Closure material volume = (41 A)(43,560 SF/A)
(3.6667 feet)/(27 CF/CY) = 242,540 CY
Duration = (242,540 CY)/(75 CYF/hr) = 3,234 hrs
System B_0322 landfill surface area portion
= 67.3 SF [BJ0322, E4]
(2) Dump trucks, 16 ton
Fuel consumption = 7.5 gal/hr [Estimate]
(2)(3,234 hrs)(7.5 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL)(67.3 SF)/(1,785,960 SF) = 2.09E8 J
(1) Bulldozer, 200 HP [Similar to Caterpillar 973]
Fuel consumption = 8.5 gal/hr [Caterpillar, 1986]
(3,234 hrs)(8.5 gal/hr)/(55 gal/BBL)(6.28E9 J/BBL)
(67.3 SF)/(1,785,960 SF) = 1.18E8 J
Total F1 equipment units = 1.02E10 J

G. Goods.

G1. Equipment for demolition debris placement and compaction.

Landfill equipment:
(1) Bulldozer, Caterpillar D-8
Use = 54 hours/month
(1) Front-end loader, 2.5 CY
Use = 67 hours/ month
Monthly Alachua County construction and demolition landfill debris = 2.60E6 lb
System B_0322 weight = 209,200 lb [BC0322]
(1) Bulldozer, Caterpillar D-8
Weight = 12,500 lb [Caterpillar, 1986]
Useful life = 15,000 hrs [Caterpillar, 1986]
(54 hrs/mo)/15,000 hrs)(209,200 lb)
/(2.60E6 lb/mo)(12,500 lb)(453.6 g/lb)
= 1.64E3 g
(1) Front-end loader, 2.5 CY
Weight = 21,500 lb [Estimate]
Useful life = 15,000 hrs [Caterpillar, 1986]
(67 hrs/mo)/(15,000 hrs)(209,200 lb)
/(2.60E6 lb/mo)(21,500 lb)(453.6 g/lb)
= 3.51E3 g

G1. Equipment for construction and demolition debris landfill closure.

Alachua County construction and demolition landfill land surface area capped = 41 acres

B-15 crew at borrow [R. S. Means Company, 1992]

(2) Dump trucks, 16 ton

(1) Bulldozer, 200 HP

Duration = (242,540 CY)/(75 CYF/hr) = 3,234 hrs

System B_0322 landfill surface area portion = 67.3 SF [BJ0322, E4]

(2) Dump trucks, 16 ton

Weight = 19,120 lb [BH0322, G1]

Useful life = 15,000 hrs [Estimate]

(2)(3,234 hrs)/(15,000 hrs)(67.3 SF)/(1,785,960 SF) (19,120 lb)(453.6 g/lb) = 1.41E2 g

(1) Bulldozer, 200 HP

Weight = 53,856 lb [Caterpillar, 1986]

Useful life = 10,000 hrs [Caterpillar, 1986]

(3234 hrs)/(10,000 hrs)(67.3 SF)/(1,785,960 SF) (53,856 lb)(453.6 g/lb) = 2.98E2 g

Total G1 equipment units = 5.59E3 g

G3. Materials.

Six feet high, three strand, barbed-wire fence on three sides of 41 acre Alachua County construction and demolition landfill.

Alachua County construction and demolition landfill land surface area capped = 41 acres

System B_0322 landfill surface area portion = 67.3 SF [BJ0322, E4]

Fence Length = 4,000 LF [Estimate]

Fence weight = 7.5 lb/LF [Estimate]

(4,000 LF)(7.5 lb/LF)(453.6 g/lb)(67.3 SF) /(1,785,960 SF) = 5.13E2 g

S. Services.

S1. Labor for demolition debris placement and compaction.

Alachua County construction and demolition landfill debris = 2.60E6 lb/mo

System B_0322 weight = 209,200 lb [BC0322]

Crew labor = 1,040 hours/month

Average 1990 labor salary = $6.00/hr

(1,040 hrs)($6.00/hr)(209,200 lb)/(2.60E6 lb/mo) = 5.02E2 $

S1. Labor for construction and demolition debris landfill closure.

Alachua County construction and demolition landfill land surface area capped = 41 acres

System B_0322 landfill surface area portion = 67.3 SF [BJ0322, E4]

Crew labor = $0.94/CY [R. S. Means Company, 1990]

Landfill closure volume = 242,540 CY [BJ0322, F1]

(242,540 CY)($0.94/CY)(67.3 SF)/(1,785,960 SF) = 8.59E0 $

Total S1 labor units = 5.11E2 $

S2. Labor for monitoring.

Monitoring labor = $110,000/year in 1990 dollars

Alachua County construction and demolition landfill land surface area capped = 41 acres

System B_0322 landfill surface area portion = 67.3 SF [BJ0322, E4]

($110,000/yr)(67.3 SF)/(1,785,960 SF) = 4.15E0 $/yr

TABLE F-32. BJ0411.

Note	Item	Raw Units g,J,$	Transformity sej/unit	Solar EMERGY sej
E	ENVIRONMENT			2.49E11/yr
E1	Atmosphere	NA		
E2	Ecol. Prod.	NA		
E3	Energy	NA		
E4	Land	2.49E11J/yr	1	2.49E11/yr
E5	Water	NA		
F	FUEL ENERGY			5.84E15
F1	Equipment	8.85E10 J	6.60E4	5.84E15
F2	Facilities	NA		
G	GOODS			3.32E14
G1	Equipment	4.84E4 g	6.70E9	3.24E14
G2	Facilities	NA		
G3	Materials	4.44E3 g	1.80E9	7.99E12
G4	Tools	NA		
S	SERVICES			8.82E15
S1	Labor	4.41E3 $	2.00E12	8.82E15
S2	Labor	35.90 $/yr	2.00E12	7.18E13/yr

BJ0411 EMERGY INPUT CALCULATION BACK-UP

Disposal phase calculations are based on data obtained during February 11, 1992 and June 8, 1992 interviews with John H. Carter, Assistant Public Works Director, Waste Management, Alachua County Public Works Department, Gainesville, Florida.

E. Environment.

E4. Land.

Alachua County construction and demolition landfill land surface area = 40 acres
Alachua County construction and demolition landfill depth = 70 feet
Alachua County construction and demolition landfill capacity
= (40 A)(43,560 SF/A)(70 ft)/(27 CF/CY)
= 4.52E6 CY
Ratio of land surface area/CY of landfill capactiy
= (40 A)(43,560 SF/A)/(4.52E6 CY)
= 0.386 SF/CY
Compacted demolition debris weight = 1,200 lb/CY
System B_0411 weight = 1.81E6 lb [BC0411]
Calculation of B_0411 landfill surface area portion
= (1.81E6 lb)/(1,200 lb/CY)(0.386 SF/CY)
= 582 SF
Avg. net absorbed solar radiation = 110 kcal/cm^2/yr [Odum, 1990]
Annual landfill surface sunlight calculations =
(Landfill surface area)(Average of insolation)
= (582 SF)(929.03 cm^2/SF)(110 kcal/cm^2/yr)
(4186 J/kcla) = 2.49E11 J/yr

F. Fuel energy.

F1. Equipment for demolition debris placement and compaction.

Landfill equipment:
(1) Bulldozer, Caterpillar D-8
Use = 54 hours/month
(1) Front-end loader, 2.5 CY
Use = 67 hours/ month
Alachua County construction and demolition landfill debris = 2.60E6 lb/mo
System B_0411 weight = 1.81E6 lb [BC0411]
(1) Bulldozer, Caterpillar D-8
Fuel consumption = 15 gal/hr [Caterpillar, 1986]
((1.81E6 lb)/(2.60E6 lb/mo)(54 hrs/mo)
(15 gal/hr))/(55 gal/BBL)(6.28E9 J/BBL)
= 6.44E10 J
(1) Front-end loader, 2.5 CY [Similar to Caterpillar 936]

Fuel consumption = 4 gal/hr [Caterpiller, 1986]

((1.81E6 lb)/(2.60E6 lb/mo)(67 hrs/mo)
(4 gal/hr))/(55 gal/BBL)(6.28E9 J/BBL)
= 2.13E10 J

F1. Equipment for construction and demolition debris landfill closure.

Closure material: 24 inches of topsoil over 8 inches of clay over 12 inches of sand. [Estimate]
Alachua County construction and demolition landfill land surface area capped = 41 acres
B-15 crew at borrow [R. S. Means Company, 1992]
(2) Dump trucks, 16 ton
(1) Bulldozer, 200 HP
Closure material haul distance = 2 miles [Estimate]
Crew output = 75 CY/hr [R. S. Means Company, 1992]
Closure material volume = (41 A)(43,560 SF/A)
(3.6667 feet)/(27 CF/CY) = 242,540 CY
Duration = (242,540 CY)/(75 CYF/hr) = 3,234 hrs
System B_0411 landfill surface area portion = 582 SF [BJ0411, E4]
(2) Dump trucks, 16 ton
Fuel consumption = 7.5 gal/hr [Estimate]
(2)(3,234 hrs)(7.5 gal/hr)/(55 gal/BBL)
(6.28E9 J/BBL)(582 SF)/(1,785,960 SF) = 1.81E9 J
(1) Bulldozer, 200 HP [Similar to Caterpillar 973]
Fuel consumption = 8.5 gal/hr [Caterpillar, 1986]
(3,234 hrs)(8.5 gal/hr)/(55 gal/BBL)(6.28E9 J/BBL)
(582 SF)/(1,785,960 SF) = 1.02E9 J

Total F1 equipment units = 8.85E10 J

G. Goods.

G1. Equipment for demolition debris placement and compaction.

Landfill equipment:
(1) Bulldozer, Caterpillar D-8
Use = 54 hours/month
(1) Front-end loader, 2.5 CY
Use = 67 hours/ month
Monthly Alachua County construction and demolition landfill debris = 2.60E6 lb
System B_0411 weight = 1.81E6 lb [BC0411]
(1) Bulldozer, Caterpillar D-8
Weight = 12,500 lb [Caterpillar, 1986]
Useful life = 15,000 hrs [Caterpillar, 1986]
(54 hrs/mo)/15,000 hrs)(1.81E6 lb)
/(2.60E6 lb/mo)(12,500 lb)(453.6 g/lb)
= 1.42E4 g
(1) Front-end loader, 2.5 CY
Weight = 21,500 lb [Estimate]
Useful life = 15,000 hrs [Caterpillar, 1986]
(67 hrs/mo)/(15,000 hrs)(1.81E6 lb)
/(2.60E6 lb/mo)(21,500 lb)(453.6 g/lb)
= 3.04E4 g

G1. Equipment for construction and demolition debris landfill closure.
Alachua County construction and demolition landfill land surface area capped = 41 acres
B-15 crew at borrow [R. S. Means Company, 1992]
(2) Dump trucks, 16 ton
(1) Bulldozer, 200 HP
Duration = (242,540 CY)/(75 CYF/hr) = 3,234 hrs
System B_0411 landfill surface area portion = 582 SF [BJ0411, E4]
(2) Dump trucks, 16 ton
Weight = 19,120 lb [BH0322, G1]
Useful life = 15,000 hrs [Estimate]
(2)(3,234 hrs)/(15,000 hrs)(582 SF)/(1,785,960 SF) (19,120 lb)(453.6 g/lb) = 1.22E3 g
(1) Bulldozer, 200 HP [BJ0322, F1]
Weight = 53,856 lb [Caterpillar, 1986]
Useful life = 10,000 hrs [Caterpillar, 1986]
(3,234 hrs)/(10,000 hrs)(582 SF)/(1,785,960 SF) (53,856 lb)(453.6 g/lb) = 2.58E3 g
Total G1 equipment units = 4.84E4 g

G3. Materials.
Six feet high, three strand, barbed-wire fence on three sides of 41 acre Alachua County construction and demolition landfill.
Alachua County construction and demolition landfill land surface area capped = 41 acres
System B_0411 landfill surface area portion = 582 SF [BJ0411, E4]
Fence Length = 4,000 LF [Estimate]
Fence weight = 7.5 lb/LF [Estimate]
(4,000 LF)(7.5 lb/LF)(453.6 g/lb)(582 SF) /(1,785,960 SF) = 4.44E3 g

S. Services.

S1. Labor for demolition debris placement and compaction.
Alachua County construction and demolition landfill debris = 2.60E6 lb/mo
System B_0411 weight = 1.81E6 lb [BC0411]
Crew labor = 1,040 hours/month
Average 1990 labor salary = $6.00/hr
(1,040 hrs)($6.00/hr)(1.81E6 lb)/(2.60E6 lb/mo) = 4.34E3 $

S1. Labor for construction and demolition debris landfill closure.
Alachua County construction and demolition landfill land surface area capped = 41 acres
System B_0411 landfill surface area portion = 582 SF [BJ0411, E4]
Crew labor = $0.94/CY [R. S. Means Company, 1990]
Landfill closure volume = 242,540 CY [BJ0322, F1]
(242,540 CY)($0.94/CY)(582 SF)/(1,785,960 SF) = 74.30E0
Total S1 labor units = 4.41E3 $

S2. Labor for monitoring.
Monitoring labor = $110,000/year in 1990 dollars
Alachua County construction and demolition landfill land surface area capped = 41 acres
System B_0411 landfill surface area portion = 582 SF [BJ0411, E4]
($110,000/yr)(582 SF)/(1,785,960 SF) = 35.90E0 $/yr

APPENDIX G

SIMULATION PROGRAM

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NOTE  EVE DESIGNATION

NOTE  A         ALTERNATIVE
NOTE   F        PHASE
NOTE    0111    UNIFORMAT CODE OF ACCOUNTS SYSTEM
NOTE        E   EMERGY INPUT SOURCE

NOTE  TIMES
N   TIME=1984                 ANALYSIS BASELINE YEAR

NOTE  ALTERNATIVE A
N   TIME_AD=1987
N   TIME_AE=1987.5
N   TIME_AF=1989
N   TIME_AG=2039
N   TIME_AH=2039.5
N   TIME_AI=2040
N   TIME_AJ=2040

NOTE  ALTERNATIVE B
N   TIME_BD=1987
N   TIME_BE=1987.5
N   TIME_BF=1989
N   TIME_BG=2039
N   TIME_BH=2039.5
N   TIME_BI=2040
N   TIME_BJ=2040

NOTE        TRANSFORMITIES (sej/Joule or sej/gram)
C   TAL=1.60E10          ALUMINUM INGOTS (g)
C   TAS=3.47E5           ASPHALT (J)
C   TCE=3.30E10          CEMENT (g)
C   TCO=2.40E8           CONCRETE (g)
C   TCP=6.80E10          COPPER (g)
C   TEL=1.59E5           ELECTRICITY (J)
C   TGL=8.40E8           GLASS (g)
C   TFE=1.80E9           IRON (g)
C   TMA=6.70E9           MACHINERY (g)
C   TNG=4.80E4           NATURAL GAS (J)
C   TOI=5.30E4           OIL (J)
C   TPA=2.15E5           PAPER (J)
C   TPP=6.60E4           PETROLEUM PRODUCT (J)
C   TPL=3.80E8           PLASTIC (g)
C   TRU=4.30E9           RUBBER (g)
C   TST=1.80E9           STEEL (g)
C   TTS=6.30E4           TOPSOIL (J)
C   TWC=6.66E5           WATER, CONSUMER (J)
C   TWW=4.10E4           WATER, WASTE (J)
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C   TWD=3.49E4            WOOD (J)
C   TZI=6.80E10           ZINC ALLOYS (g)

NOTE                      ALTERNATIVE A
NOTE   EMERGY OF MATERIAL TRANSFORMITY PHASES A-C.
NOTE         RESOURCE EMERGY (sej)
A   AC0322E.K=(AC0322PP)(TPP)+(AC0322ST)(TST)
C     AC0322PP=5.08E10
C     AC0322ST=9.08E7
A   AC0411E.K=(AC0411CO)(TCO)+(AC0411ST)(TST)
C     AC0411CO=7.19E8
C     AC0411ST=1.70E7

NOTE   TOTAL EMERGY OF MATERIAL TRANSFORMITY PHASES A-C.

A   AA_C.K=AC0322E.K+AC0411E.K

NOTE   ENVIRONMENTAL IMPACT EMERGY OF PHASE D: DESIGN
A   AD0322.K=AD0322E+AD0322F+AD0322G+AD0322S
C     AD0322E=1.41E13
C     AD0322F=1.48E14
C     AD0322G=0
C     AD0322S=4.56E15
A   AD0411.K=AD0411E+AD0411F+AD0411G+AD0411S
C     AD0411E=2.02E13
C     AD0411F=2.12E14
C     AD0411G=0
C     AD0411S=6.52E15
A   AD.K=AD0322.K+AD0411.K

NOTE   ENVIRONMENTAL IMPACT EMERGY OF PHASE E: COMPONENT
NOTE   PRODUCTION
A   AE0322.K=AE0322E+AE0322F+AE0322G+AE0322S
C     AE0322E=0
C     AE0322F=2.75E15
C     AE0322G=3.35E15
C     AE0322S=2.40E16
A   AE0411.K=AE0411E+AE0411F+AE0411G+AE0411S
C     AE0411E=0
C     AE0411F=2.06E15
C     AE0411G=2.04E14
C     AE0411S=2.02E15
A   AE.K=AE0322.K+AE0411.K

NOTE   ENVIRONMENTAL IMPACT EMERGY OF PHASE F: CONSTRUCTION
A   AF0322.K=AF0322E+AF0322F+AF0322G+AF0322S
C     AF0322E=0
C     AF0322F=6.49E15
C     AF0322G=1.01E15
C     AF0322S=2.84E16
A   AF0411.K=AF0411E+AF0411F+AF0411G+AF0411S
C     AF0411E=0
C     AF0411F=2.02E15
C     AF0411G=3.06E13
```

```
C     AF0411S=1.72E17
A   AF.K=AF0322.K+AF0411.K

NOTE   ENVIRONMENTAL IMPACT EMERGY OF PHASE G: USE
A   AG0322.K=AG0322E+AG0322F+AG0322G+AG0322S
C     AG0322E=0
C     AG0322F=0
C     AG0322G=0
C     AG0322S=0
A   AG0411.K=AG0411E+AG0411F+AG0411G+AG0411S
C     AG0411E=0
C     AG0411F=0
C     AG0411G=0
C     AG0411S=0
A   AG.K=AG0322.K+AG0411.K

NOTE   ENVIRONMENTAL IMPACT EMERGY OF PHASE H: DEMOLITION
A   AH0322.K=AH0322E+AH0322F+AH0322G+AH0322S
C     AH0322E=0
C     AH0322F=3.21E16
C     AH0322G=4.76E15
C     AH0322S=5.56E16
A   AH0411.K=AH0411E+AH0411F+AH0411G+AH0411S
C     AH0411E=0
C     AH0411F=1.60E16
C     AH0411G=2.38E15
C     AH0411S=2.78E16
A   AH.K=AH0322.K+AH0411.K

NOTE   ENVIRONMENTAL IMPACT EMERGY OF PHASE I: NATURAL
NOTE   RESOURCE RECYCLING
A   AI0322.K=AI0322E+AI0322F+AI0322G+AI0322S
C     AI0322E=0
C     AI0322F=0
C     AI0322G=0
C     AI0322S=0
A   AI0411.K=AI0411E+AI0411F+AI0411G+AI0411S
C     AI0411E=0
C     AI0411F=0
C     AI0411G=0
C     AI0411S=0
A   AI.K=AI0322.K+AI0411.K

NOTE   ENVIRONMENTAL IMPACT EMERGY OF PHASE J: DISPOSAL
A   AJ0322.K=AJ0322E+AJ0322F+AJ0322G+AJ0322S
N     AJ0322E=1.21E12
C     AJ0322F=6.46E14
C     AJ0322G=3.67E13
C     AJ0322S=1.33E15
A   AJ0411.K=AJ0411E+AJ0411F+AJ0411G+AJ0411S
C     AJ0411E=9.21E12
C     AJ0411F=5.23E15
C     AJ0411G=2.97E14
C     AJ0411S=1.08E16
```

```
A   AJ.K=AJ0322.K+AJ0411.K

NOTE   PHASE CLIPS OF ALTERNATIVE A
A  ADT.K=CLIP(AD.K,0,TIME.K,TIME_AD)
A  AET.K=CLIP(AE.K,0,TIME.K,TIME_AE)
A  AFT.K=CLIP(AF.K,0,TIME.K,TIME_AF)
A  AGT.K=CLIP(AG.K,0,TIME.K,TIME_AG)
A  AHT.K=CLIP(AH.K,0,TIME.K,TIME_AH)
A  AIT.K=CLIP(AI.K,0,TIME.K,TIME_AI)
A  AJT.K=CLIP(AJ.K,0,TIME.K,TIME_AJ)

NOTE  TOTAL ENVIRONMENTAL IMPACT EMERGY OF ALTERNATIVE A
A  ATEIE.K=AA_C.K+ADT.K+AET.K+AFT.K+AGT.K+AHT.K+AIT.K+AJT.K


NOTE                         ALTERNATIVE B

NOTE   EMERGY OF MATERIAL TRANSFORMITY PHASES A-C.
NOTE   RESOURCE EMERGY (sej)
A   BC0322E.K=(BC0322PP)(TPP)+(BC0322ST)(TST)
C      BC0322PP=5.30E10
C      BC0322ST=9.49E7
A BC0411E.K=(BC0411CO)(TCO)+(BC0411PP)(TPP)+(BC0411ST)(TST)^
               +(BC0411WD)(TWD)
C      BC0411CO=7.89E8
C      BC0411PP=1.99E10
C      BC0411ST=1.96E7
C      BC0411WD=1.80E11

NOTE   TOTAL EMERGY OF MATERIAL TRANSFORMITY PHASES A-C.

A   BA_C.K=BC0322E.K+BC0411E.K

NOTE   ENVIRONMENTAL IMPACT EMERGY OF PHASE D: DESIGN
A   BD0322.K=BD0322E+BD0322F+BD0322G+BD0322S
C      BD0322E=1.44E13
C      BD0322F=1.50E14
C      BD0322G=0
C      BD0322S=4.64E15
A   BD0411.K=BD0411E+BD0411F+BD0411G+BD0411S
C      BD0411E=2.08E13
C      BD0411F=2.18E14
C      BD0411G=0
C      BD0411S=6.70E15
A   BD.K=BD0322.K+BD0411.K

NOTE   ENVIRONMENTAL IMPACT EMERGY OF PHASE E: COMPONENT
NOTE   PRODUCTION
A   BE0322.K=BE0322E+BE0322F+BE0322G+BE0322S
C      BE0322E=0
C      BE0322F=3.30E15
C      BE0322G=3.50E15
C      BE0322S=2.52E16
A   BE0411.K=BE0411E+BE0411F+BE0411G+BE0411S
```

```
C      BE0411E=0
C      BE0411F=0
C      BE0411G=0
C      BE0411S=0
A    BE.K=BE0322.K+BE0411.K

NOTE    ENVIRONMENTAL IMPACT EMERGY OF PHASE F: CONSTRUCTION
A    BF0322.K=BF0322E+BF0322F+BF0322G+BF0322S
C      BF0322E=0
C      BF0322F=6.67E15
C      BF0322G=1.10E15
C      BF0322S=2.96E16
A    BF0411.K=BF0411E+BF0411F+BF0411G+BF0411S
C      BF0411E=0
C      BF0411F=2.41E15
C      BF0411G=5.89E14
C      BF0411S=5.60E16
A    BF.K=BF0322.K+BF0411.K

NOTE    ENVIRONMENTAL IMPACT EMERGY OF PHASE G: USE
A    BG0322.K=BG0322E+BG0322F+BG0322G+BG0322S
C      BG0322E=0
C      BG0322F=0
C      BG0322G=0
C      BG0322S=0
A    BG0411.K=BG0411E+BG0411F+BG0411G+BG0411S
C      BG0411E=0
C      BG0411F=2.41E13
C      BG0411G=2.41E14
C      BG0411S=5.12E15
A    BG.K=BG0322.K+BG0411.K

NOTE    ENVIRONMENTAL IMPACT EMERGY OF PHASE H: DEMOLITION
A    BH0322.K=BH0322E+BH0322F+BH0322G+BH0322S
C      BH0322E=0
C      BH0322F=3.21E16
C      BH0322G=4.76E15
C      BH0322S=5.56E16
A    BH0411.K=BH0411E+BH0411F+BH0411G+BH0411S
C      BH0411E=0
C      BH0411F=2.81E16
C      BH0411G=4.17E15
C      BH0411S=4.92E16
A    BH.K=BH0322.K+BH0411.K

NOTE    ENVIRONMENTAL IMPACT EMERGY OF PHASE I: NATURAL
        RESOURCE RECYCLING
A    BI0322.K=BI0322E+BI0322F+BI0322G+BI0322S
C      BI0322E=0
C      BI0322F=0
C      BI0322G=0
C      BI0322S=0
A    BI0411.K=BI0411E+BI0411F+BI0411G+BI0411S
C      BI0411E=0
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C      BI0411F=0
C      BI0411G=0
C      BI0411S=0
A    BI.K=BI0322.K+BI0411.K

NOTE    ENVIRONMENTAL IMPACT EMERGY OF PHASE J: DISPOSAL
A    BJ0322.K=BJ0322E+BJ0322F+BJ0322G+BJ0322S
C      BJ0322E=1.27E12
C      BJ0322F=6.73E14
C      BJ0322G=3.84E13
C      BJ0322S=1.39E15
A    BJ0411.K=BJ0411E+BJ0411F+BJ0411G+BJ0411S
C      BJ0411E=1.10E13
C      BJ0411F=5.84E15
C      BJ0411G=3.32E14
C      BJ0411S=1.20E16
A    BJ.K=BJ0322.K+BJ0411.K

NOTE    PHASE CLIPS FOR ALTERNATIVE B
A   BDT.K=CLIP(BD.K,0,TIME.K,TIME_BD)
A   BET.K=CLIP(BE.K,0,TIME.K,TIME_BE)
A   BFT.K=CLIP(BF.K,0,TIME.K,TIME_BF)
A   BGT.K=CLIP(BG.K,0,TIME.K,TIME_BG)
A   BHT.K=CLIP(BH.K,0,TIME.K,TIME_BH)
A   BIT.K=CLIP(BI.K,0,TIME.K,TIME_BI)
A   BJT.K=CLIP(BJ.K,0,TIME.K,TIME_BJ)

NOTE  TOTAL ENVIRONMENTAL IMPACT EMERGY OF ALTERNATIVE B
A   BTEIE.K=BA_C.K+BDT.K+BET.K+BFT.K+BGT.K+BHT.K+BIT.K+BJT.K

NOTE  CONTROL STATEMENT
SAVE AA_C,ADT,AET,AFT,AGT,AHT,AIT,AJT,ATEIE
SAVE BA_C,BDT,BET,BFT,BGT,BHT,BIT,BJT,BTEIE

SPEC DT=0.5/LENGTH=2084/SAVPER=0.5/PLTPER=0.5
```

APPENDIX H

CASE STUDY APPLICATION TABULAR SIMULATION OUTPUT

```
TIME           1984.      1985.      1986.      1987.      1988.

AA_C        370.e15    370.e15    370.e15    370.e15    370.e15
ADT              0.         0.         0.  11.47e15    11.47e15
AET              0.         0.         0.         0.   34.38e15
AFT              0.         0.         0.         0.         0.
AGT              0.         0.         0.         0.         0.
AHT              0.         0.         0.         0.         0.
AIT              0.         0.         0.         0.         0.
AJT              0.         0.         0.         0.         0.
ATEIE       370.e15    370.e15    370.e15   381.4e15   415.8e15

BA_C       406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT              0.         0.         0.  11.74e15   11.74e15
BET              0.         0.         0.         0.     32.e15
BFT              0.         0.         0.         0.         0.
BGT              0.         0.         0.         0.         0.
BHT              0.         0.         0.         0.         0.
BIT              0.         0.         0.         0.         0.
BJT              0.         0.         0.         0.         0.
BTEIE      406.6e15   406.6e15   406.6e15   418.3e15   450.3e15


TIME           1989.      1990.      1991.      1992.      1993.

AA_C        370.e15    370.e15    370.e15    370.e15    370.e15
ADT        11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET        34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT         210.e15    210.e15    210.e15    210.e15    210.e15
AGT              0.         0.         0.         0.         0.
AHT              0.         0.         0.         0.         0.
AIT              0.         0.         0.         0.         0.
AJT              0.         0.         0.         0.         0.
ATEIE      625.8e15   625.8e15   625.8e15   625.8e15   625.8e15

BA_C       406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT        11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET          32.e15     32.e15     32.e15     32.e15     32.e15
BFT        96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT              0.         0.         0.         0.         0.
BHT              0.         0.         0.         0.         0.
BIT              0.         0.         0.         0.         0.
BJT              0.         0.         0.         0.         0.
BTEIE      546.7e15   546.7e15   546.7e15   546.7e15   546.7e15
```

```
TIME          1994.      1995.      1996.      1997.      1998.

AA_C        370.e15    370.e15    370.e15    370.e15    370.e15
ADT        11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET        34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT         210.e15    210.e15    210.e15    210.e15    210.e15
AGT              0.         0.         0.         0.         0.
AHT              0.         0.         0.         0.         0.
AIT              0.         0.         0.         0.         0.
AJT              0.         0.         0.         0.         0.
ATEIE      625.8e15   625.8e15   625.8e15   625.8e15   625.8e15

BA_C       406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT        11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET          32.e15     32.e15     32.e15     32.e15     32.e15
BFT        96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT              0.         0.         0.         0.         0.
BHT              0.         0.         0.         0.         0.
BIT              0.         0.         0.         0.         0.
BJT              0.         0.         0.         0.         0.
BTEIE      546.7e15   546.7e15   546.7e15   546.7e15   546.7e15


TIME          1999.      2000.      2001.      2002.      2003.

AA_C        370.e15    370.e15    370.e15    370.e15    370.e15
ADT        11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET        34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT         210.e15    210.e15    210.e15    210.e15    210.e15
AGT              0.         0.         0.         0.         0.
AHT              0.         0.         0.         0.         0.
AIT              0.         0.         0.         0.         0.
AJT              0.         0.         0.         0.         0.
ATEIE      625.8e15   625.8e15   625.8e15   625.8e15   625.8e15

BA_C       406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT        11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET          32.e15     32.e15     32.e15     32.e15     32.e15
BFT        96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT              0.         0.         0.         0.         0.
BHT              0.         0.         0.         0.         0.
BIT              0.         0.         0.         0.         0.
BJT              0.         0.         0.         0.         0.
BTEIE      546.7e15   546.7e15   546.7e15   546.7e15   546.7e15
```

```
TIME             2004.       2005.       2006.       2007.       2008.

AA_C           370.e15     370.e15     370.e15     370.e15     370.e15
ADT          11.47e15    11.47e15    11.47e15    11.47e15    11.47e15
AET          34.38e15    34.38e15    34.38e15    34.38e15    34.38e15
AFT            210.e15     210.e15     210.e15     210.e15     210.e15
AGT                 0.          0.          0.          0.          0.
AHT                 0.          0.          0.          0.          0.
AIT                 0.          0.          0.          0.          0.
AJT                 0.          0.          0.          0.          0.
ATEIE        625.8e15    625.8e15    625.8e15    625.8e15    625.8e15

BA_C         406.6e15    406.6e15    406.6e15    406.6e15    406.6e15
BDT          11.74e15    11.74e15    11.74e15    11.74e15    11.74e15
BET             32.e15      32.e15      32.e15      32.e15      32.e15
BFT          96.37e15    96.37e15    96.37e15    96.37e15    96.37e15
BGT                 0.          0.          0.          0.          0.
BHT                 0.          0.          0.          0.          0.
BIT                 0.          0.          0.          0.          0.
BJT                 0.          0.          0.          0.          0.
BTEIE        546.7e15    546.7e15    546.7e15    546.7e15    546.7e15


TIME             2009.       2010.       2011.       2012.       2013.

AA_C           370.e15     370.e15     370.e15     370.e15     370.e15
ADT          11.47e15    11.47e15    11.47e15    11.47e15    11.47e15
AET          34.38e15    34.38e15    34.38e15    34.38e15    34.38e15
AFT            210.e15     210.e15     210.e15     210.e15     210.e15
AGT                 0.          0.          0.          0.          0.
AHT                 0.          0.          0.          0.          0.
AIT                 0.          0.          0.          0.          0.
AJT                 0.          0.          0.          0.          0.
ATEIE        625.8e15    625.8e15    625.8e15    625.8e15    625.8e15

BA_C         406.6e15    406.6e15    406.6e15    406.6e15    406.6e15
BDT          11.74e15    11.74e15    11.74e15    11.74e15    11.74e15
BET             32.e15      32.e15      32.e15      32.e15      32.e15
BFT          96.37e15    96.37e15    96.37e15    96.37e15    96.37e15
BGT                 0.          0.          0.          0.          0.
BHT                 0.          0.          0.          0.          0.
BIT                 0.          0.          0.          0.          0.
BJT                 0.          0.          0.          0.          0.
BTEIE        546.7e15    546.7e15    546.7e15    546.7e15    546.7e15
```

```
TIME           2014.      2015.      2016.      2017.      2018.

AA_C         370.e15    370.e15    370.e15    370.e15    370.e15
ADT         11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET         34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT          210.e15    210.e15    210.e15    210.e15    210.e15
AGT               0.         0.         0.         0.         0.
AHT               0.         0.         0.         0.         0.
AIT               0.         0.         0.         0.         0.
AJT               0.         0.         0.         0.         0.
ATEIE       625.8e15   625.8e15   625.8e15   625.8e15   625.8e15

BA_C        406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT         11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET           32.e15     32.e15     32.e15     32.e15     32.e15
BFT         96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT               0.         0.         0.         0.         0.
BHT               0.         0.         0.         0.         0.
BIT               0.         0.         0.         0.         0.
BJT               0.         0.         0.         0.         0.
BTEIE       546.7e15   546.7e15   546.7e15   546.7e15   546.7e15


TIME           2019.      2020.      2021.      2022.      2023.

AA_C         370.e15    370.e15    370.e15    370.e15    370.e15
ADT         11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET         34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT          210.e15    210.e15    210.e15    210.e15    210.e15
AGT               0.         0.         0.         0.         0.
AHT               0.         0.         0.         0.         0.
AIT               0.         0.         0.         0.         0.
AJT               0.         0.         0.         0.         0.
ATEIE       625.8e15   625.8e15   625.8e15   625.8e15   625.8e15

BA_C        406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT         11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET           32.e15     32.e15     32.e15     32.e15     32.e15
BFT         96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT               0.         0.         0.         0.         0.
BHT               0.         0.         0.         0.         0.
BIT               0.         0.         0.         0.         0.
BJT               0.         0.         0.         0.         0.
BTEIE       546.7e15   546.7e15   546.7e15   546.7e15   546.7e15
```

```
TIME            2024.      2025.      2026.      2027.      2028.

AA_C          370.e15    370.e15    370.e15    370.e15    370.e15
ADT          11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET          34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT           210.e15    210.e15    210.e15    210.e15    210.e15
AGT                0.         0.         0.         0.         0.
AHT                0.         0.         0.         0.         0.
AIT                0.         0.         0.         0.         0.
AJT                0.         0.         0.         0.         0.
ATEIE        625.8e15   625.8e15   625.8e15   625.8e15   625.8e15

BA_C         406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT          11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET            32.e15     32.e15     32.e15     32.e15     32.e15
BFT          96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT                0.         0.         0.         0.         0.
BHT                0.         0.         0.         0.         0.
BIT                0.         0.         0.         0.         0.
BJT                0.         0.         0.         0.         0.
BTEIE        546.7e15   546.7e15   546.7e15   546.7e15   546.7e15


TIME            2029.      2030.      2031.      2032.      2033.

AA_C          370.e15    370.e15    370.e15    370.e15    370.e15
ADT          11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET          34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT           210.e15    210.e15    210.e15    210.e15    210.e15
AGT                0.         0.         0.         0.         0.
AHT                0.         0.         0.         0.         0.
AIT                0.         0.         0.         0.         0.
AJT                0.         0.         0.         0.         0.
ATEIE        625.8e15   625.8e15   625.8e15   625.8e15   625.8e15

BA_C         406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT          11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET            32.e15     32.e15     32.e15     32.e15     32.e15
BFT          96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT                0.         0.         0.         0.         0.
BHT                0.         0.         0.         0.         0.
BIT                0.         0.         0.         0.         0.
BJT                0.         0.         0.         0.         0.
BTEIE        546.7e15   546.7e15   546.7e15   546.7e15   546.7e15
```

```
TIME           2034.     2035.     2036.     2037.     2038.

AA_C         370.e15   370.e15   370.e15   370.e15   370.e15
ADT        11.47e15  11.47e15  11.47e15  11.47e15  11.47e15
AET        34.38e15  34.38e15  34.38e15  34.38e15  34.38e15
AFT          210.e15   210.e15   210.e15   210.e15   210.e15
AGT               0.        0.        0.        0.        0.
AHT               0.        0.        0.        0.        0.
AIT               0.        0.        0.        0.        0.
AJT               0.        0.        0.        0.        0.
ATEIE      625.8e15  625.8e15  625.8e15  625.8e15  625.8e15

BA_C       406.6e15  406.6e15  406.6e15  406.6e15  406.6e15
BDT        11.74e15  11.74e15  11.74e15  11.74e15  11.74e15
BET          32.e15    32.e15    32.e15    32.e15    32.e15
BFT        96.37e15  96.37e15  96.37e15  96.37e15  96.37e15
BGT               0.        0.        0.        0.        0.
BHT               0.        0.        0.        0.        0.
BIT               0.        0.        0.        0.        0.
BJT               0.        0.        0.        0.        0.
BTEIE      546.7e15  546.7e15  546.7e15  546.7e15  546.7e15


TIME           2039.     2040.     2041.     2042.     2043.

AA_C         370.e15   370.e15   370.e15   370.e15   370.e15
ADT        11.47e15  11.47e15  11.47e15  11.47e15  11.47e15
AET        34.38e15  34.38e15  34.38e15  34.38e15  34.38e15
AFT          210.e15   210.e15   210.e15   210.e15   210.e15
AGT               0.        0.        0.        0.        0.
AHT               0.  138.6e15  138.6e15  138.6e15  138.6e15
AIT               0.        0.        0.        0.        0.
AJT               0.  18.35e15  18.35e15  18.35e15  18.35e15
ATEIE      625.8e15  782.8e15  782.8e15  782.8e15  782.8e15

BA_C       406.6e15  406.6e15  406.6e15  406.6e15  406.6e15
BDT        11.74e15  11.74e15  11.74e15  11.74e15  11.74e15
BET          32.e15    32.e15    32.e15    32.e15    32.e15
BFT        96.37e15  96.37e15  96.37e15  96.37e15  96.37e15
BGT        5385.e12  5385.e12  5385.e12  5385.e12  5385.e12
BHT               0.  173.9e15  173.9e15  173.9e15  173.9e15
BIT               0.        0.        0.        0.        0.
BJT               0.  20.29e15  20.29e15  20.29e15  20.29e15
BTEIE      552.1e15  746.3e15  746.3e15  746.3e15  746.3e15
```

```
TIME          2044.      2045.      2046.      2047.      2048.

AA_C        370.e15    370.e15    370.e15    370.e15    370.e15
ADT        11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET        34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT         210.e15    210.e15    210.e15    210.e15    210.e15
AGT              0.         0.         0.         0.         0.
AHT        138.6e15   138.6e15   138.6e15   138.6e15   138.6e15
AIT              0.         0.         0.         0.         0.
AJT        18.35e15   18.35e15   18.35e15   18.35e15   18.35e15
ATEIE      782.8e15   782.8e15   782.8e15   782.8e15   782.8e15

BA_C       406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT        11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET          32.e15     32.e15     32.e15     32.e15     32.e15
BFT        96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT        5385.e12   5385.e12   5385.e12   5385.e12   5385.e12
BHT        173.9e15   173.9e15   173.9e15   173.9e15   173.9e15
BIT              0.         0.         0.         0.         0.
BJT        20.29e15   20.29e15   20.29e15   20.29e15   20.29e15
BTEIE      746.3e15   746.3e15   746.3e15   746.3e15   746.3e15


TIME          2049.      2050.      2051.      2052.      2053.

AA_C        370.e15    370.e15    370.e15    370.e15    370.e15
ADT        11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET        34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT         210.e15    210.e15    210.e15    210.e15    210.e15
AGT              0.         0.         0.         0.         0.
AHT        138.6e15   138.6e15   138.6e15   138.6e15   138.6e15
AIT              0.         0.         0.         0.         0.
AJT        18.35e15   18.35e15   18.35e15   18.35e15   18.35e15
ATEIE      782.8e15   782.8e15   782.8e15   782.8e15   782.8e15

BA_C       406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT        11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET          32.e15     32.e15     32.e15     32.e15     32.e15
BFT        96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT        5385.e12   5385.e12   5385.e12   5385.e12   5385.e12
BHT        173.9e15   173.9e15   173.9e15   173.9e15   173.9e15
BIT              0.         0.         0.         0.         0.
BJT        20.29e15   20.29e15   20.29e15   20.29e15   20.29e15
BTEIE      746.3e15   746.3e15   746.3e15   746.3e15   746.3e15
```

```
TIME             2054.      2055.      2056.      2057.      2058.

AA_C           370.e15    370.e15    370.e15    370.e15    370.e15
ADT          11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET          34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT            210.e15    210.e15    210.e15    210.e15    210.e15
AGT                0.         0.         0.         0.         0.
AHT          138.6e15   138.6e15   138.6e15   138.6e15   138.6e15
AIT                0.         0.         0.         0.         0.
AJT          18.35e15   18.35e15   18.35e15   18.35e15   18.35e15
ATEIE        782.8e15   782.8e15   782.8e15   782.8e15   782.8e15

BA_C         406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT          11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET            32.e15     32.e15     32.e15     32.e15     32.e15
BFT          96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT          5385.e12   5385.e12   5385.e12   5385.e12   5385.e12
BHT          173.9e15   173.9e15   173.9e15   173.9e15   173.9e15
BIT                0.         0.         0.         0.         0.
BJT          20.29e15   20.29e15   20.29e15   20.29e15   20.29e15
BTEIE        746.3e15   746.3e15   746.3e15   746.3e15   746.3e15


TIME             2059.      2060.      2061.      2062.      2063.

AA_C           370.e15    370.e15    370.e15    370.e15    370.e15
ADT          11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET          34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT            210.e15    210.e15    210.e15    210.e15    210.e15
AGT                0.         0.         0.         0.         0.
AHT          138.6e15   138.6e15   138.6e15   138.6e15   138.6e15
AIT                0.         0.         0.         0.         0.
AJT          18.35e15   18.35e15   18.35e15   18.35e15   18.35e15
ATEIE        782.8e15   782.8e15   782.8e15   782.8e15   782.8e15

BA_C         406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT          11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET            32.e15     32.e15     32.e15     32.e15     32.e15
BFT          96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT          5385.e12   5385.e12   5385.e12   5385.e12   5385.e12
BHT          173.9e15   173.9e15   173.9e15   173.9e15   173.9e15
BIT                0.         0.         0.         0.         0.
BJT          20.29e15   20.29e15   20.29e15   20.29e15   20.29e15
BTEIE        746.3e15   746.3e15   746.3e15   746.3e15   746.3e15
```

```
TIME            2064.      2065.      2066.      2067.      2068.

AA_C          370.e15    370.e15    370.e15    370.e15    370.e15
ADT          11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET          34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT           210.e15    210.e15    210.e15    210.e15    210.e15
AGT                0.         0.         0.         0.         0.
AHT          138.6e15   138.6e15   138.6e15   138.6e15   138.6e15
AIT                0.         0.         0.         0.         0.
AJT          18.35e15   18.35e15   18.35e15   18.35e15   18.35e15
ATEIE        782.8e15   782.8e15   782.8e15   782.8e15   782.8e15

BA_C         406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT          11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET            32.e15     32.e15     32.e15     32.e15     32.e15
BFT          96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT          5385.e12   5385.e12   5385.e12   5385.e12   5385.e12
BHT          173.9e15   173.9e15   173.9e15   173.9e15   173.9e15
BIT                0.         0.         0.         0.         0.
BJT          20.29e15   20.29e15   20.29e15   20.29e15   20.29e15
BTEIE        746.3e15   746.3e15   746.3e15   746.3e15   746.3e15


TIME            2069.      2070.      2071.      2072.      2073.

AA_C          370.e15    370.e15    370.e15    370.e15    370.e15
ADT          11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET          34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT           210.e15    210.e15    210.e15    210.e15    210.e15
AGT                0.         0.         0.         0.         0.
AHT          138.6e15   138.6e15   138.6e15   138.6e15   138.6e15
AIT                0.         0.         0.         0.         0.
AJT          18.35e15   18.35e15   18.35e15   18.35e15   18.35e15
ATEIE        782.8e15   782.8e15   782.8e15   782.8e15   782.8e15

BA_C         406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT          11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET            32.e15     32.e15     32.e15     32.e15     32.e15
BFT          96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT          5385.e12   5385.e12   5385.e12   5385.e12   5385.e12
BHT          173.9e15   173.9e15   173.9e15   173.9e15   173.9e15
BIT                0.         0.         0.         0.         0.
BJT          20.29e15   20.29e15   20.29e15   20.29e15   20.29e15
BTEIE        746.3e15   746.3e15   746.3e15   746.3e15   746.3e15
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```
TIME            2074.      2075.      2076.      2077.      2078.

AA_C          370.e15    370.e15    370.e15    370.e15    370.e15
ADT          11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET          34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT           210.e15    210.e15    210.e15    210.e15    210.e15
AGT                0.         0.         0.         0.         0.
AHT          138.6e15   138.6e15   138.6e15   138.6e15   138.6e15
AIT                0.         0.         0.         0.         0.
AJT          18.35e15   18.35e15   18.35e15   18.35e15   18.35e15
ATEIE        782.8e15   782.8e15   782.8e15   782.8e15   782.8e15

BA_C         406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT          11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET            32.e15     32.e15     32.e15     32.e15     32.e15
BFT          96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT          5385.e12   5385.e12   5385.e12   5385.e12   5385.e12
BHT          173.9e15   173.9e15   173.9e15   173.9e15   173.9e15
BIT                0.         0.         0.         0.         0.
BJT          20.29e15   20.29e15   20.29e15   20.29e15   20.29e15
BTEIE        746.3e15   746.3e15   746.3e15   746.3e15   746.3e15


TIME            2079.      2080.      2081.      2082.      2083.

AA_C          370.e15    370.e15    370.e15    370.e15    370.e15
ADT          11.47e15   11.47e15   11.47e15   11.47e15   11.47e15
AET          34.38e15   34.38e15   34.38e15   34.38e15   34.38e15
AFT           210.e15    210.e15    210.e15    210.e15    210.e15
AGT                0.         0.         0.         0.         0.
AHT          138.6e15   138.6e15   138.6e15   138.6e15   138.6e15
AIT                0.         0.         0.         0.         0.
AJT          18.35e15   18.35e15   18.35e15   18.35e15   18.35e15
ATEIE        782.8e15   782.8e15   782.8e15   782.8e15   782.8e15

BA_C         406.6e15   406.6e15   406.6e15   406.6e15   406.6e15
BDT          11.74e15   11.74e15   11.74e15   11.74e15   11.74e15
BET            32.e15     32.e15     32.e15     32.e15     32.e15
BFT          96.37e15   96.37e15   96.37e15   96.37e15   96.37e15
BGT          5385.e12   5385.e12   5385.e12   5385.e12   5385.e12
BHT          173.9e15   173.9e15   173.9e15   173.9e15   173.9e15
BIT                0.         0.         0.         0.         0.
BJT          20.29e15   20.29e15   20.29e15   20.29e15   20.29e15
BTEIE        746.3e15   746.3e15   746.3e15   746.3e15   746.3e15
```

```
TIME          2084.

AA_C        370.e15
ADT        11.47e15
AET        34.38e15
AFT         210.e15
AGT              0.
AHT        138.6e15
AIT              0.
AJT        18.35e15
ATEIE      782.8e15

BA_C       406.6e15
BDT        11.74e15
BET          32.e15
BFT        96.37e15
BGT        5385.e12
BHT        173.9e15
BIT              0.
BJT        20.29e15
BTEIE      746.3e15
```

APPENDIX I

CASE STUDY APPLICATION EVE EMERGY INDICES

EMERGY per unit of built environment alternative

Exterior wall construction system 0411 of alternative A:

$$\frac{\text{Total system EMERGY from Table 3-4 (a)}}{\text{Total system area}} = \frac{4.51\text{E}17 \text{ sej}}{19{,}189 \text{ SF}}$$

$$= 2.35\text{E}13 \text{ sej/SF}$$

Exterior wall construction system 0411 of alternative B:

$$\frac{\text{Total system EMERGY from Table 3-4 (b)}}{\text{Total system area}} = \frac{4.03\text{E}17 \text{ sej}}{19{,}189 \text{ SF}}$$

$$= 2.10\text{E}13 \text{ sej/SF}$$

EMERGY per unit of built environment production output

$$= \frac{\text{Solar EMERGY required from Table 3-5}}{\text{Total gross production output}}$$

Alert Shelter Complex production output = 2 missions/day [Estimate]

Use phase = 50 yrs. [EVE simulation program]

Alternative A (Systems 0322 & 0411):

$$\frac{7.83\text{E}17 \text{ sej}}{(50 \text{ yrs.})(365 \text{ days/yr.})(2 \text{ missions/day})} = 2.15\text{E}13 \text{ sej/mission}$$

Alternative B (Systems 0322 & 0411):

$$\frac{7.46\text{E}17 \text{ sej}}{(50 \text{ yrs.})(365 \text{ days/yr.})(2 \text{ missions/day})} = 2.04\text{E}13 \text{ sej/mission}$$

APPENDIX J

GLOSSARY

Available energy. Energy with the potential to do work (Odum, 1991).

Built environment. All human-made objects (alternatives) on earth that consume environment, fuel energy, goods, and services inputs.

Embodied energy. Coal equivalent BTUs of fuels used directly and indirectly and assigned to particular materials or products in proportion to their costs using input-output methods of Hannon et al. (1978) and Herendeen (1973).

EMERGY. All the available energy that was used in the work of making a product expressed in units of one type of energy (Odum, 1991).

EMERGY analysis. Calculation and comparison of EMERGY inputs and outputs of a system.

EMERGY investment ratio. The ratio of the EMERGY fed back from the economy to the EMERGY inputs from the free environment (Odum, 1991).

EMERGY signature. A graphical representation of empower.

Emjoule. The unit of EMERGY which has the dimensions of the energy previously used (grams-centimeter squared per second squared)(Odum, 1991).

Empower. Flux of EMERGY production and use.

Energy. A property of all systems which can be turned into heat and measured in heat units (Calories, BTUs or Joules)(Odum, 1991).

Energy hierarchy. The convergence and transformation of energy from many small units into smaller amounts of higher-level types of energy (often in units of larger size) with greater ability to interact with and control smaller units (Odum, 1991).

Energy systems language. A general systems language for representing units and connections for processing materials, energy, and information of any system; diagrammatic representation of systems with a set of symbols (Appendix C) that have precise mathmatical and energetic meanings (Odum, 1991).

Maximum empower principle. An explanation of the structure and function observed in self-organizing systems (energy transformations, hierarchical patterns, feedback (recycle) controls, amplifier actions, etc.). Systems prevail that draw in more available energy and use it more efficiently than alternatives.

Net EMERGY yield ratio. The EMERGY of production output (yield) divided by the EMERGY of those inputs to the process that are fed back from the economy (Odum, 1991).

Solar emjoule (sej). The solar joules previously required through direct and indirect transformations to produce all the inputs for a service or product.

Solar transformity. The equivalent solar energy that would be required to generate (create) a unit of an object or resource efficiently and rapidly (Odum, 1991).

Sustainable use. Resource use that can be continued by society in the long run because the use level and system design allow resources to be renewed by natural or man-aided processes (Odum, 1991).

Transformity. The EMERGY of one type required to make a unit of energy of another type (Odum, 1991).

Wealth. Usable products and services however produced (Odum, 1991)

REFERENCES

American Institute of Architects. (1987). Contractual issues. The architect's handbook of professional practice (Vol. 2.2). Washington, DC: Author.

American Institute of Architects. (1992, April). Environmental resource guide subscription. Washington, DC: Author.

American Institute of Steel Construction. (1980). Manual of steel construction. Chicago: Author.

American Society for Testing and Materials. (1989). Standard practice for measuring life-cycle costs of buildings and building systems (Designation: E917-89. Philadelphia: Author.

American Society for Testing and Materials. (1990). Building economics. Philadelphia: Author.

Brown, M. T., & McClanahan, T. R. (1992). Report to The Cousteau Society: Emergy analysis perspectives of Thailand and Mekong River dam proposals. Gainesville: University of Florida, Center for Wetlands and Water Resources.

Caterpillar Corporation. (1986). Caterpillar performance handbook. Peoria, IL: Author.

Collier, C. A., & Ledbetter, W. B. (1982). Engineering cost analysis. New York: Harper & Row.

Dell'Isola, A. J., & Kirk, S. J. (1981). Life cycle costing for design professionals. New York: McGraw-Hill.

Doherty, S. J., Odum, H. T., & Nilsson, P. O. (1992). Final report to the Swedish State Power Board, 1992: Systems analysis of the solar emergy basis for forest alternatives in Sweden. Gainesville: University of Florida, Center for Environmental Policy.

General Services Administration. (1981). Project estimating procedures (Publication No. PBS P 3440.5). Washington, DC: Author.

Hannon, B. M., Stein, R. G., Segal, B. Z., Deibert, P. F., Buckley, M., & Nathan, D. (1977). Energy use for building construction, supplement (Report No. C00-2791-4). Washington, DC: U.S. Department of Energy.

Hannon, B. M., Stein, R. G., Segal, B. Z., & Serber, D. (1976). Energy use for building construction, final report (Report No. C00-2791-3). Washington, DC: U.S. Department of Energy.

Hannon, B. M., Stein, R. G., Segal, B. Z., & Serber, D. (1977). Energy use for building construction. Champaign-Urbana: University of Illinois, Center for Advanced Computation.

Hannon, B. M., Stein, R. G., Segal, B. Z., & Serber, D. (1978). Energy and labor in the construction sector. Science, 202, 837-847.

Hanscomb Associates, Inc. (1986). Value engineering management report: Alert Shelter Complex, Homestead Air Force Base, Florida. Atlanta: Author.

Haviland, D. S. (1978). Life cycle cost analysis 2: Using it in practice. Washington, DC: American Institute of Architects.

Herendeen, R. A. (1973). An energy input-output matrix for the U. S.: User's guide. Urbana: University of Illinois, Center for Advanced Computation.

Hufschmidt, M. M., James, D. E., Meister, A. D., Bower, J. A., & Dixon, J. A. (1983). Environment, natural system, and development: An economic valuation guide. Baltimore: Johns Hopkins University Press.

International Conference of Building Officials. (1991). 1991 Uniform building code. Whittier, CA: Author.

Johnson, R. (1990). The economics of building. New York: John Wiley & Sons.

Kibert, C. J., Roudebush, W. H., & Waller, D. L. (1991, January/February/March). Environmental value engineering. Value World, pp. 2-5.

Kirk, S. J., & Spreckelmeyer, K. F. (1988). Creative design decisions: A systematic approach to problem solving in architecture. New York: Van Nostrand Reinhold.

Lawson, W. R. (1992). Capital energy costs of building and recycling of building materials. Pre-proceedings of First International Symposium of CIB Working Commission W82: Future Studies in Construction. Espoo, Finland: YRT.

Leonov, A. L., & Stenhouse, D. S. (1979). Embodied energy in building equipment and construction materials. Proceedings of the 1979 National Conference on Technology for Energy Conservation. Silver Spring, MD: Information Transfer, Inc.

Lotka, A. J. (1925). Elements of physical biology. Baltimore: Williams & Wilkins.

Mockler, R. J. (1989). Knowledge-based systems for management decisions. Englewood Cliffs, NJ: Prentice-Hall.

Norton, D. J., & Slonecker, E. T. (1990, November/December). The ecological geography of EMAP. Geo Info Systems, pp. 32-43.

Odum, H. T. (1971). Environment, power, and society. New York: Wiley Interscience.

Odum, H. T. (1983). Systems ecology: An introduction. New York: John Wiley & Sons.

Odum, H. T. (1988). Energy, environment and public policy: A guide to the analysis of systems (UNEP Regional Seas Reports and Studies No. 95). Nairobi, Kenya: United Nations Environment programme.

Odum, H. T. (1991). EMERGY analysis of shrimp mariculture in Ecuador. Narragansett: University of Rhode Island, Coastal Resources Center.

Odum, H. T. (in press). EMERGY and public policy. New York: McGraw-Hill.

Odum, H. T., & Odum, E. C. (1981). Energy basis for man and nature. New York: McGraw-Hill.

Project Time & Cost, Inc. (1988). Ready to advertise submittal estimate: Alert Shelter Complex, Homestead Air Force Base, Florida. Atlanta, GA: Author.

R. S. Means Company. (1990). Means building construction cost data 1990. Kingston, MA: Author.

R. S. Means Company. (1992). Means building construction cost data 1992. Kingston, MA: Author.

Richardson, G. P., & Pugh, A. L. III. (1981). Introduction to systems dynamics modeling with DYNAMO. Cambridge, MA: The MIT Press.

Roose, R. W. (Ed.). (1978). Handbook of energy conservation for mechanical systems in buildings. New York: Van Nostrand Reinhold.

Roudebush, W. H. (1991). An energy systems model and computer simulation of the built environment as related to land availability. Unpublished paper.

Scienceman, D. (1987). Energy and emergy. In Environmental economics. G. Pillet, and T. Murota, Eds. Geneva, Switzerland: Roland Leimgruber.

Siddens, R. S. (Ed.). (1989). Walker's building estimators reference book (23rd ed.). Lisle, IL: Frank R. Walker Company.

Simmons, H. L. (1985). The specifications writer's handbook. New York: John Wiley & Sons.

Stein, B., Reynolds, J. S., & McGuinness, W. J. (1986). Mechanical and electrical equipment for buildings (7th ed.). New York: John Wiley & Sons.

Topp, K. O. (1985). Closure and postclosure cost estimates for sanitary landfills in Florida. Unpublished master's thesis. Gainesville: University of Florida.

United States Department of Energy. (1981). Handbook of energy use for building construction (DOE Publication DOE/CE/20220-1). Washington, DC: U. S. Government Printing Office.

World Commission on Environment and Development. (1987). Our common future. New York: Oxford University Press.

Zimmerman, L. W., & Hart, G. D. (1982). Value engineering: A practical approach for owners, designers and contractors. New York: Van Nostrand Reinhold.

BIOGRAPHICAL SKETCH

Wilfred H. Roudebush was born August 19, 1947, in Canton, Ohio, to Betty and Ernest Roudebush. He grew up in Carrollton, Ohio, and attended Carrollton High School. Upon graduation in 1965 he began working for the Federal Bureau of Investigation (FBI) in Washington, DC. After a year with the FBI he resigned and began working as a structural steel detailer at Macomber, Inc., in Canton, Ohio.

In 1968 he entered the five-year architectural degree program at Kent State University in Kent, Ohio. Upon graduation in 1973, he moved to Colorado Springs, Colorado, where he and his wife, Christine, were married. While in Colorado Springs, he worked for the architectural firm Herald Holding and Associates, the Colorado Springs Urban Renewal Authority, and the architectural firm Barber and Yergensen, Inc.

In January 1978, he left Barber and Yergensen, Inc., to begin work with Burns and McDonnell, Inc., in Kansas City, Missouri. As senior project architect at Burns and McDonnell, he was responsible for the architectural portion of several substantial projects. While at Burns and McDonnell, he entered the construction management degree program in the School of Architectural Engineering at the University of Kansas. About a year before completion of his Master of Science degree, he left Burns and McDonnell and became sole proprietor of his own architectural firm in Kansas City, Missouri.

In April 1983 he moved with his wife and children to Winter Park, Florida, where he was employed by the architectural firm of Rogers, Lovelock, and Fritz, Inc. (RLF). He took a leave of absence from RLF during the spring semester of 1988 to teach at the M. E. Rinker, Sr. School of Building Construction, which is within the College of Architecture at the University of Florida.

He entered the Doctor of Philosophy degree program in the College of Architecture in the fall semester of 1988. Program course work was completed the spring semester of 1991. He graduated in 1992.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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